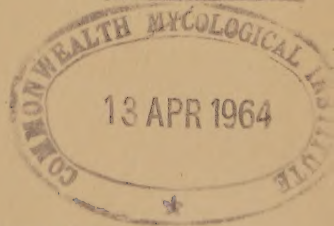
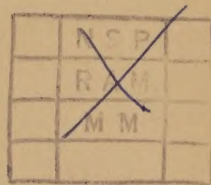




COMMITTEE OF THE PRIVY COUNCIL FOR
AGRICULTURAL RESEARCH

REPORT OF THE
AGRICULTURAL RESEARCH COUNCIL
FOR THE YEAR 1959-60

*Presented to Parliament by the Minister for Science
by Command of Her Majesty
May, 1961*



LONDON
HER MAJESTY'S STATIONERY OFFICE
NINE SHILLINGS NET

Cmnd. 1362

RESEARCH STUDENTSHIPS AND FELLOWSHIPS

	<i>Page</i>
Research Studentships	68
Fellowships	69

SPECIAL RESEARCH GRANTS

Grants current on 31st March, 1960	70
---	----

REPORTS FROM AGRICULTURAL RESEARCH INSTITUTES AND UNITS

SOIL

Rothamsted Experimental Station	78
Macaulay Institute for Soil Research	81
Soil Survey of Great Britain	83
A.R.C. Unit of Soil Physics	84

PLANT BREEDING

Plant Breeding Institute... ..	85
Welsh Plant Breeding Station	88
Scottish Plant Breeding Station	92
A.R.C. Unit of Biometrical Genetics	93

PLANT PHYSIOLOGY

A.R.C. Unit of Plant Physiology	95
A.R.C. Unit of Plant Morphogenesis and Nutrition	97

PLANT GROWTH SUBSTANCES

A.R.C. Unit of Plant Growth Substances and Systemic Fungicides	98
--	----

PASTURE

Grassland Research Institute	100
-------------------------------------	-----

HORTICULTURE, GLASSHOUSE CROPS AND FRUIT

John Innes Institute	102
Glasshouse Crops Research Institute	104
East Malling Research Station... ..	107
Agricultural and Horticultural Research Station, Long Ashton	110
Scottish Horticultural Research Institute	113
Wye College, Department of Hop Research	115

VEGETABLES

National Vegetable Research Station	117
--	-----

WEEDS

A.R.C. Unit of Experimental Agronomy	119
---	-----

PESTS AND DISEASES (*see also* PLANT GROWTH SUBSTANCES, *above*)

A.R.C. Unit of Insect Physiology	122
A.R.C. Virus Research Unit	123

HILL FARMING

Hill Farming Research Organisation	125
---	-----

ANIMAL BREEDING

A.R.C. Animal Breeding Research Organisation	128
A.R.C. Unit of Reproductive Physiology and Biochemistry	131
A.R.C. Unit of Animal Genetics	133

	<i>Page</i>
ANIMAL DISEASES	
A.R.C. Field Station	137
Foot-and-Mouth Disease Research Institute (Animal Virus Diseases)	144
Animal Diseases Research Association	148
ANIMAL PHYSIOLOGY AND NUTRITION	
Rowett Research Institute	152
A.R.C. Institute of Animal Physiology	157
A.R.C. Unit of Embryology	161
A.R.C. Unit of Microbiology	162
DAIRYING	
National Institute for Research in Dairying	163
Hannah Dairy Research Institute	167
POULTRY	
A.R.C. Poultry Research Centre	171
Houghton Poultry Research Station	174
AGRICULTURAL ENGINEERING	
National Institute of Agricultural Engineering	177
National Institute of Agricultural Engineering Scottish Station ...	180
FARM BUILDINGS	
A.R.C. Farm Buildings Unit	181
FOOD	
Ditton Laboratory	182
Low Temperature Research Station	186
Pest Infestation Laboratory	190
STATISTICS	
A.R.C. Unit of Statistics	193
A.R.C. Statistics Group	194
RADIOBIOLOGY	
A.R.C. Radiobiological Laboratory	195
STATE-AIDED AGRICULTURAL RESEARCH INSTITUTES	198
AGRICULTURAL RESEARCH COUNCIL INSTITUTES AND UNITS	199
SCIENTIFIC STAFF ATTACHED TO UNIVERSITIES OR RESEARCH INSTITUTES ...	200
THE COUNCIL'S COMMITTEES AND CONFERENCES	201

THE REPORT OF THE COMMITTEE OF PRIVY COUNCIL FOR AGRICULTURAL RESEARCH FOR THE YEAR 1959-60

TO THE QUEEN'S MOST EXCELLENT MAJESTY,
MAY IT PLEASE YOUR MAJESTY,

We, the Lords of the Committee for Agricultural Research of Your Majesty's Privy Council, humbly submit to Your Majesty a Report of our proceedings during the year from 1st April, 1959 to 31st March, 1960.

2. During the financial year 1959-60, Parliament provided a total of £4,822,910 as a grant-in-aid of the Agricultural Research Fund, the original grant-in-aid of £4,545,000 being increased by a revised estimate presented in July, 1959, which took account of the additional expenditure involved in the transfer to the Council of responsibility for food research. The total was based on estimated current expenditure of £4,528,015 gross, receipts of £284,205 and capital expenditure of £579,100 on buildings and special equipment.

3. During the year under report we appointed two new members to the Agricultural Research Council: Francis William Rogers Brambell, B.A., D.Sc., Ph.D., F.R.S., Professor of Zoology in the University College of North Wales, who filled the vacancy caused by the retirement, after ten years' service on the Council, of Professor Sir Solly Zuckerman, C.B., M.A., M.D., D.Sc., F.R.S., and the Lord Netherthorpe of Anston, B.Sc., LL.D., on the retirement of Mr. F. Rayns, C.B.E., M.A. Mr. David Lowe, C.B.E., F.R.S.E., was appointed for a second term of five years and continues to act as Deputy Chairman of the Council. Mr. B. C. Engholm succeeded Mr. J. Hensley as a representative of the Ministry of Agriculture, Fisheries and Food and was subsequently succeeded in that capacity by Mr. H. G. Button.

4. On 30th June, 1960, Sir William K. Slater, K.B.E., D.Sc., F.R.I.C., F.R.S., retired from the Secretaryship of the Council, a post which he had held with great distinction for eleven years. He has been succeeded by Ernest Gordon Cox, T.D., D.Sc., F.Inst.P., F.R.I.C., F.R.S., Professor of Inorganic and Structural Chemistry in the University of Leeds, who accordingly relinquished his membership of the Council.

5. Professor P. B. Medawar, F.R.S., a member of the Council, was awarded the Nobel Prize for Medicine, jointly with Sir Macfarlane Burnet, F.R.S., for his distinguished contribution in the field of acquired immunological tolerance. Professor Medawar was also awarded the Royal Medal of the Royal Society.

6. We have received from the Agricultural Research Council a report, which is submitted herewith, upon the progress of its work during the year ended 31st March, 1960. This again shows an increase in the amount spent on agricultural research and reflects expenditure on food research, which is now the responsibility of the Council.

7. Discussions between the Council, the University Grants Committee and the universities on the financing of research in the universities have proceeded to the point at which it is hoped that the universities themselves will, from 1962, assume financial responsibility for well-established research previously supported by the Council and thus enable a larger proportion of the Council's funds to be used for the development of new and promising lines of work.

8. Consideration is being given to the long-term needs for research on food and to arrangements for the establishment of a Meat Research Organisation.

9. The comprehensive monitoring of radioactivity in the food chain has continued; in view of the fall in the content of strontium 90, the Council will review its present arrangements in order to make available a larger proportion of the scientific effort for research, while maintaining the survey at an adequate level.

10. The initial response of farmers to the Council's experimental scheme for the development and testing of farm buildings in different parts of the country has been most encouraging.

11. A new Weed Research Organisation has been established to expand the Council's facilities for the assessment of new herbicides, for studies of factors that bear on the choice of chemicals and the time and method of their application.

12. To meet the foreseeable increase in the demands on the Council's statistical service a new electronic computer has been ordered which will be installed at Rothamsted Experimental Station in 1962.

On behalf of the Lords of the Committee for Agricultural Research of Your Majesty's Privy Council.

HAILSHAM,
Minister for Science.

E. G. COX,
*Secretary to the Committee of Privy Council
for Agricultural Research.*

26th April, 1961.

THE REPORT OF THE AGRICULTURAL RESEARCH COUNCIL FOR THE YEAR 1959-60

To the Lords of the Committee of Privy Council for Agricultural Research.

May it please your Lordships,

The Agricultural Research Council begs leave to submit the following Report upon its proceedings during the period from 1st April, 1959 to 31st March, 1960.

INTRODUCTION

RESEARCH IN UNIVERSITIES

The Council attaches great importance to its links with the scientific departments of the universities, to which it looks for the development of new lines of research, for the education of future members of the agricultural research service, and for the provision of a substantial proportion of the senior scientists who give most valuable help by service on the Council and its committees.

The Council supports research in the universities in three main ways: firstly, by setting up Units built around a professor or reader of distinction in a subject of interest to the Council; secondly, by the provision, for a limited period of years, of block grants or special research grants, mainly for recurrent expenditure and the employment of assistants; and thirdly, by the provision of non-recurrent grants for the purchase of expensive equipment. The Council's policy with regard to Units, which has remained unchanged for some years, calls for no comment at the present time, but some mention should be made of developments under the other two heads.

Special research grants are made in response to applications from university workers who wish to undertake new researches which cannot be financed from current university funds. These grants, which cover a wide range of topics (*see p. 70*), constitute a flexible means of providing, with a minimum of delay, either initial assistance for new and promising lines of research which may be expected, if successful, to continue for many years, or full assistance for short-term investigations which are especially timely. Reference was made in last year's report to the problem of how best to ensure the continuance of projects of the first sort which have fulfilled their early promise and which, on any reasonable assessment of their scientific merits, ought certainly to be allowed to continue; the funds available to the Council for assisting research in university departments are limited, and if a fair proportion is to be used each year to encourage new research they cannot—save in the exceptional circumstances in which the setting up of a Unit is justified—be earmarked to provide continuing support over an indefinite period for any one line of work. The further discussions on this subject which have taken place between the Research Councils and the University Grants Committee have resulted in an agreement

that universities can, if they wish, make financial provision for the continuance of grant-aided work in the quinquennial estimates they submit to the University Grants Committee. In accordance with this arrangement the Council has been discussing with the various universities the future of individual research projects which are currently supported by grants from the Council and which appear to be developing into an important long-term interest of the university department concerned. On the whole these discussions are proceeding smoothly and although one or two universities have expressed doubts whether they will obtain sufficient funds to enable them to take over the projects in question it is hoped that these misgivings will prove unfounded and that, as a result of the assumption of responsibility for well-established researches by the universities themselves from 1962, the Council will be in a much stronger position to help them to develop new and fruitful lines of work that emerge in the course of the quinquennium which begins in that year. In principle the new arrangements provide a very important opportunity for the University Grants Committee, the Universities and the Research Councils to co-operate in strengthening the country's research effort, and it is to be hoped that when the working of the arrangements for 1962 is reviewed the results will justify their continuance in future quinquennia; this occasion for quinquennial stocktaking will undoubtedly give both the Universities and the Research Councils a valuable opportunity not only to confirm the importance of flourishing researches but also, in some cases, to make the less pleasant but no less important decision to discontinue investigations which have not fulfilled their early promise.

Acting on a recommendation in the Annual Report for 1957-58 of the Advisory Council on Scientific Policy, the Council has obtained the agreement of the Treasury to an extension of the scope of its assistance to universities by providing non-recurring grants for the purchase of special items of research equipment costing between £1,000 and £10,000. This new dispensation is complementary to the existing system of research grants (which usually provide for the employment of research assistants and other recurring expenditure required for a specific research project) and is intended to enable a university department to procure relatively expensive equipment which could not normally be purchased from its annual departmental budget and which, while not tied to any specific project, will enable the department to develop more advantageously important lines of research in which it is interested.

RESEARCH IN OVERSEAS TERRITORIES

At the instance of the Overseas Research Council we have discussed with the Treasury the extent to which the Agricultural Research Council can assist in the maintenance and encouragement of agricultural research in the emerging territories of the Commonwealth. The Treasury has recognised that it is part of the responsibility of the Agricultural Research Council to meet a reasonable number of requests for the secondment of research scientists to overseas governments, particularly the newly independent territories of the Commonwealth, and has agreed that in working out its staffing requirements the Council should take account of the fact that at any one time a number of its staff will be serving elsewhere on secondment. It has also been agreed that, as one means of encouraging key scientists at present working for an overseas government to continue doing so, the Council may make conditional offers of future employ-

ment to a limited number of such scientists whom it would be undesirable to draw away from their present employment but who would, if this came to an end, be particularly suitable either for secondment to other overseas posts or for filling vacancies under the Council.

FOOD RESEARCH

On 1st July, 1959, the Council assumed formal responsibility for food research and took over from the Department of Scientific and Industrial Research the Low Temperature Research Station at Cambridge, the Ditton Laboratory at East Malling and the Pest Infestation Laboratory at Slough. Since the transfer the three stations have continued their programmes of research. Meanwhile, the Council has been considering the long-term needs for research on food. It has been encouraged to find that its view of the importance of meat research has been fully supported by the Food Research Advisory Committee set up by the Minister of Agriculture, Fisheries and Food and the Secretary of State for Scotland. Arrangements for the establishment of a Meat Research Organisation are receiving consideration and plans are also being prepared for dealing with the problems of research in food other than meat. Close relationships have been established with the departments responsible for food and this has enabled arrangements to be made for the transfer of certain food research projects from the Ministry of Agriculture, Fisheries and Food to the Council.

The four Research Associations concerned with food have exercised their option to remain, for the time being, with the Department of Scientific and Industrial Research. The Council is confident, however, that it will be able to maintain close and harmonious relations with them and regular meetings are being held between the directors of the Research Associations and of the Council's own stations concerned with food research.

MONITORING OF RADIOACTIVITY IN THE FOOD CHAIN

Although the new laboratory buildings at Letcombe Regis have not yet been completed, sufficient facilities are now available to enable the Radiobiological Laboratory to carry out a comprehensive monitoring survey of food, herbage and soil for the most important radioactive components of fall-out as well as to continue its programme of research into the movement of radionuclides in the food chain. The regular reports giving the results of the monitoring survey have continued to be published at approximately six-monthly intervals. The period under review saw a rise of strontium 90 in milk to peak values in the early summer of 1959, following nuclear test explosions in the autumn of 1958. Fortunately, later measurements show a fall in the content of strontium 90 and, in the absence of further nuclear tests, it is expected that this fall will continue. In these circumstances the Council intends to review its present monitoring and sampling procedure to ensure that, while the survey is maintained at an adequate level, a larger proportion of the time of the scientific staff is devoted to research.

A Committee appointed by the Medical Research Council has reviewed the possible hazards to man of nuclear and allied radiation and has issued a report (Cmnd. 1225) in which new assessments are made of the permissible doses of radiation to various sections of the population and new permissible levels laid down for strontium 90 in human bone. These new levels will be used in assessing

the implication for human health of future levels of radioactive substances in food as revealed by the monitoring survey.

During the year a number of international organisations took steps to encourage greater co-operation and exchange of information between countries in the collection of monitoring data. The U.K. has participated fully in such arrangements and members of the staff of the Radiobiological Laboratory have given assistance, which has been much appreciated, both in the preparation of material and by participating in several international gatherings, notably meetings of the U.N. Scientific Committee on Effects of Atomic Radiation and a conference of experts convened by the Food and Agriculture Organisation to report on the movement of radioactive materials in the biosphere.

FARM BUILDINGS RESEARCH

In its last report, the Council set out the principles on which its policy for research on farm buildings was based. In pursuance of this policy the compilation of the bibliography of research on farm building design has been continued and successive sections have been published. It is intended that the original sections, covering publications up to 1958, should be followed in due course by supplements bringing them up-to-date.

Research on questions which bear on farm building design continues as a part of the programmes of a number of agricultural research institutes, and also in university departments with the support of special research grants. In order to facilitate the translation of the results of this research into a form suitable for application to the design of farm buildings in different parts of the country, an experimental scheme for the development and testing of new types of buildings was announced in Parliament on 16th February, 1960, and was brought into operation by the Council in the following July. Under this scheme, farmers or landowners are invited to put forward proposals for the erection of buildings, or modifications to existing buildings, incorporating new features or ideas; from the proposals put forward the Council, acting on the advice of an expert sub-committee, selects those which lend themselves to incorporation in a planned experiment under the supervision of the Council's Farm Buildings Unit. Applicants so selected carry out the building work involved, based on their own design but planned in consultation with the Unit, and are asked to collaborate with the Unit in making observations and records of the performance of the buildings during normal use. Farmers who are willing to co-operate in this way can qualify for a grant from the Council of up to half the cost of the buildings concerned. The scheme is necessarily selective, as only proposals which can conveniently be incorporated into the Unit's research programme can be accepted, and the staff available limits both the number of experiments that can be supervised at any one time and the number of farms which can be incorporated in any experiment. Although it is too early to judge the results of the scheme, the Council is very encouraged by the initial response of farmers and by their readiness to co-operate in this novel form of collaborative experiment.

WEED RESEARCH

The increasing use of selective herbicides during the last 15 years has not only had an important influence on the pattern of farming but has also led to a study of the principles underlying weed control as a rapidly developing branch

of agricultural research. After the introduction and testing of new chemicals, in which great activity is shown by commercial firms, much research is still needed to ensure that they are used most efficiently and economically in conjunction with existing or new husbandry methods and horticultural practices. This includes independent assessment of the most promising new herbicides, studies of all the plant, soil and weather factors that bear on the choice of chemicals, and the time and method of their application.

Such research has hitherto been done in the Council's Unit of Experimental Agronomy at Oxford University, along with more fundamental physiological studies of the selective action of compounds toxic to plants, and the Unit has played a leading part in the development of weed control methods. With the need for still more work on agronomic and ecological aspects of the subject, an expansion of facilities has become necessary.

Steps were accordingly taken during the year to set up a new Weed Research Organisation, under the Directorship of Dr. E. K. Woodford, with a nucleus of staff drawn from the Unit. A farm near Oxford has been acquired for the Organisation, and a laboratory and other necessary buildings are being provided. The Unit of Experimental Agronomy will continue to fulfil its primary purpose of fundamental research on selective toxicity of chemicals to plants, and the two bodies will work closely together. The Weed Research Organisation will also maintain collaboration with industry, with the National Agricultural Advisory Service and the Scottish Agricultural Advisory Services, and with the Plant Pathology Laboratory of the Ministry of Agriculture, Fisheries and Food, which administers the Agricultural Chemicals Approval Scheme.

STATISTICAL SERVICE—ROTHAMSTED EXPERIMENTAL STATION

In 1954, through the courtesy of the National Research Development Corporation, the Council was able to hire from the Corporation an "Elliott 401" Electronic Computer which was installed at Rothamsted Experimental Station. This proved a most valuable arrangement, which has greatly facilitated the analysis of experiments, not only for Rothamsted, but also for the field experimental programme of the N.A.A.S. and for a number of outside bodies both at home and overseas. In the five years that the computer has been in operation the number of experiments analysed has risen from 419 in 1955 to 2,649 in 1959. At the beginning of 1960 the "Elliott 401" was running virtually to the limit of its capacity and, in view of the increasing demands being made on the statistical service, and the need for more complicated and extensive analyses, it became apparent that a larger and more efficient machine was required. An order was accordingly placed for a Ferranti "Orion" Electronic Computer which will be installed at Rothamsted in the autumn of 1962.

The computing speed of the "Orion" is of the order of 25-50 times that of the "Elliott 401" and, with suitable ancillary equipment, the input and output of information will be about ten times that of the "Elliott." At first sight it might appear that this increase in capacity will be more than is needed by the Statistics Department of the Station. There are, however, some types of analysis which require heavy computing and which cannot be fully processed on the present machine. The improved programming facilities of the "Orion," together with its greater computing speed and larger capacity, will make it

possible for the Department to extend its statistical service, particularly in the field of genetics, in the analysis of surveys and in processing continuously-recorded data of the kind that are regularly accumulated in agricultural research laboratories.

The acquisition of this new machine will enable the Station fully to maintain the considerable contribution it has already made to the development of computer techniques in research statistics and of statistical methods which ensure that the greatest possible amount of information is obtained from experiments with a minimal increase in the experimental effort.

RETIREMENT OF SIR WILLIAM SLATER

On 30th June, 1960, Sir William Slater retired from the post of Secretary of the Council which he had filled with such conspicuous success since his appointment in 1949. During his term of office he brought to a successful conclusion the ten-year programme for the development of agricultural research approved by the Cabinet at the end of the war; new institutes have been created and existing ones expanded; links with universities have been strengthened by the establishment of a number of Units in university departments and responsibility has been accepted for new activities—notably in the fields of food research and farm buildings. The Council is deeply conscious of the great debt it owes to Sir William for his wise and imaginative guidance during these eleven years.

ADMINISTRATION AND FINANCE

1959-60

ROYAL VISIT

The National Vegetable Research Station was honoured by a visit from H.R.H. Prince Philip, Duke of Edinburgh, who opened the Station's new laboratories on 23rd October, 1959.

ROYAL SOCIETY TERCENTENARY CELEBRATIONS

The Council presented an illuminated address to the Royal Society on the occasion of its Tercentenary.

STAFF

At the close of the year under report there were 4,490 members of staff employed at the agricultural research institutes. Of this number 904 were in the Scientific Officer class, 651 in the Experimental Officer class and 892 in the Assistant (Scientific) class. The remainder were mainly in the Executive, Clerical and Industrial classes. The number of staff employed in the Council's Secretariat was 78.

SECRETARY OF THE COUNCIL

Professor E. G. Cox, F.R.S., was selected to succeed Sir William Slater, K.B.E., F.R.S., Secretary to the Council since 1949, on his impending retirement in June, 1960.

CHANGES IN DIRECTORSHIPS

Dr. A. T. R. Mattick, Acting Director of the National Institute for Research in Dairying, retired on 30th September, 1959. Professor R. G. Baskett was appointed to the Directorship on 1st August, 1959.

Professor T. Wallace, F.R.S., retired from the Directorship of the A.R.C. Unit of Plant Nutrition (Micro-Nutrients) on 30th September, 1959, and the Unit was disbanded, a number of its staff being transferred to Long Ashton Research Station.

Dr. Kenneth Smith, F.R.S., retired from the Directorship of the A.R.C. Virus Research Unit and was succeeded by Dr. R. Markham, F.R.S., on 1st January, 1960.

Dr. E. K. Woodford was appointed to the Directorship of the A.R.C. Weed Research Organisation which was set up on 1st April, 1960.

OTHER CHANGES

Sir Rudolph Peters, F.R.S., Head of the Biochemistry Department at the A.R.C. Institute of Animal Physiology, retired on 31st December, 1959, and was succeeded by Dr. D. G. Greville.

Dr. H. P. Donald, Director of the A.R.C. Animal Breeding Research Organisation, and Dr. F. R. Tubbs, Director of the East Malling Research Station, were promoted to the grade of Chief Scientific Officer on 1st April, 1959.

Dr. D. Rudd Jones and Mr. F. H. Moulton were appointed as Scientific Assistants to the Secretary of the Council on 1st November, 1959.

HONOURS AND AWARDS

Her Majesty the Queen conferred the following honours:—

C.B.E. ... Mr. W. Ness, Assistant Secretary, A.R.C. Headquarters.

C.B.E. ... Dr. J. A. B. Smith, Director, Hannah Dairy Research Institute.

O.B.E. ... Dr. E. K. Woodford, A.R.C. Unit of Experimental Agronomy.

M.B.E. ... Mr. E. W. Hobbs, Agricultural and Horticultural Research Station, Long Ashton.

Professor R. L. Wain, Honorary Director of the Council's Plant Growth Substances and Systemic Fungicides Unit, was elected a Fellow of the Royal Society.

Dr. Alan Robertson of the Council's Unit of Animal Genetics received the Research Medal for 1959 of the Royal Agricultural Society of England.

Dr. A. T. Phillipson of the Rowett Research Institute was awarded the Dalrymple Cup and Medal for 1959 by the British Veterinary Association.

Dr. A. W. Greenwood, Director of the Council's Poultry Research Centre, was elected a Fellow of the United States Poultry Science Association.

VISITING GROUPS

The following institutes received Visiting Groups during the year:—

Glasshouse Crops Research Institute, Rustington.

Hill Farming Research Organisation, Edinburgh.

A.R.C. Poultry Research Centre, Edinburgh.

Houghton Poultry Research Station, Houghton.

OVERSEAS LIAISON

The various research centres received many hundreds of visitors from overseas, some of whom spent periods of up to twelve months in further training and research. The students and research workers accommodated at the institutes included trainees under the Colombo Plan and recipients of awards from the Food and Agriculture Organisation of the United Nations, the Central Treaty Organisation and other international and government technical aid schemes, and holders of fellowships and scholarships awarded by benevolent foundations.

The Council encourages contact with developments in agricultural research in other countries by financing the attendance of research workers from this

country at international scientific conferences in different parts of the world. Notable among meetings held in 1959 were the 9th Botanical Congress in Montreal, the 5th International Conference on Plant Growth Substances in New York and the International Veterinary Congress in Madrid. The Council made some 200 grants to enable members of the agricultural research service to attend these and other conferences and to visit research centres in Europe, Canada and the U.S.A. to study developments and trends in varied fields of agricultural research.

Under an agreement negotiated by the Soviet Relations Committee of the British Council with the U.S.S.R. State Committee for Cultural Relations with Foreign Countries, useful exchanges in the field of agriculture were arranged with the Ministry of Agriculture of the U.S.S.R.

The Chairman of the Council, while in North America in the autumn of 1959, took the opportunity of discussing with officials of the U.S. Department of Agriculture and others, work related to the Council's interests in livestock. Sir William Slater, as Chairman of the Colonial Committee for Agricultural, Animal Health and Forestry Research, visited East Africa and attended a meeting of the East African Agricultural and Fisheries Research Council at Nairobi. He also took the Chair at a meeting of an F.A.O. Expert Committee on Radioactive Materials in Food and Agriculture held in Rome in December, 1959.

BUILDINGS AND PROPERTY

Several major schemes were completed during the year. These included the new administration block at the Glasshouse Crops Research Institute; extended laboratory and animal accommodation for the Nutrition Department at the Hannah Dairy Research Institute; new laboratories at the Houghton Poultry Research Station; staff canteen and common room at the Long Ashton Research Station; hydraulics laboratory at the National Institute of Agricultural Engineering; main laboratory at the National Vegetable Research Station; and extension to the sewage disposal works at the Field Station, Compton. The Council purchased the 287-acre estate of Begbroke Hill Farm, Oxford, to provide accommodation and land for the Weed Research Organisation, and a further 96 acres of land for the National Vegetable Research Station, Wellesbourne.

The major works in progress at the end of the year 1959-60 were:—

Long Ashton Research Station: new laboratories.

Macaulay Institute for Soil Research: new laboratory accommodation.

National Institute for Research in Dairying: renovations and alterations to the Manor House.

Field Station, Compton: laboratory extension.

Unit of Reproductive Physiology and Biochemistry: additional laboratory accommodation.

The Council approved in principle the following projects:—

Glasshouse Crops Research Institute: new heating system for the trial glasshouses, and a laboratory/glasshouse unit for virus, entomological and nematological work.

National Institute for Research in Dairying: new laboratory buildings (2nd wing), cowshed and milking parlour, radiobiochemistry building, small animal house, and "germ free" research facilities.

National Institute of Agricultural Engineering: new laboratory for the Field Investigation Department.

Rothamsted Experimental Station: additional building for the Statistics Department, and extension to the West Building.

Welsh Plant Breeding Station: new laboratory building for developmental genetics.

Institute of Animal Physiology: pig research laboratory.

Animal Breeding Research Organisation: new headquarters building.

Radiobiological Laboratory: new laboratories.

Unit of Plant Morphogenesis and Plant Nutrition: glasshouse accommodation.

Pest Infestation Laboratory: new laboratory and canteen.

Low Temperature Research Station: meat storage and research facilities.

Weed Research Organisation: general development of Begbroke Hill Farm including laboratories, farm buildings, etc.

LAND AGENCY SERVICE

The Council's Land Agents, Messrs. W. H. Cooke & Arkwright, have continued to provide useful advice on problems of land and estate management for State-aided research institutes throughout England and Wales and also for the Council's own establishments.

AGRICULTURAL RESEARCH FUND

The greater part of the Council's expenditure is met from the Agricultural Research Fund which is financed by a Parliamentary grant-in-aid. In the financial year ended 31st March, 1960, gross current expenditure was £4,486,874; capital expenditure on buildings and special apparatus amounted to £514,307. A grant-in-aid of £4,822,910 was voted by Parliament, of which £4,702,000 was drawn. The grant-in-aid was augmented by receipts totalling £251,169 derived from sales of livestock, produce, etc., at research institutes and units, from rents and hostel charges, and from the sale of publications and reports, as well as by contributions totalling £42,499 from Government Departments and other sources. These contributions included, *inter alia*, £15,244 from the Hops Marketing Board and the Institute of Brewing towards the cost of research on hops at Wye College; £10,000 from the Animal Health Trust towards the maintenance of the Houghton Poultry Research Station; £13,478 from the Colonial Office towards the cost of the Council's Unit of Experimental Agronomy and the maintenance of the Tropical Liaison Department of the Pest Infestation Laboratory; and £2,592 from the Colonial Office for research on insecticides at Rothamsted Experimental Station.

The allocation under main heads of the total expenditure from the Agricultural Research Fund was as follows:—

	£	Percentage of total
Administration	146,208	2·9
Research institutes and units of the Council:		
Current expenditure	1,471,217	29·4
Capital expenditure	169,719	3·4
Special research grants... ..	151,181	3·0
Studentships, training awards and fellowships (including travelling fellowships and grants for visits overseas)	46,072	0·9
Grants to independent research institutes (England and Wales):		
for current expenditure	2,672,196	53·5
for capital expenditure	344,588	6·9
	£5,001,181	100·0

GRANTS MADE FROM THE VOTE OF THE DEPARTMENT OF AGRICULTURE AND FISHERIES FOR SCOTLAND

Grants to the independent agricultural research institutes in Scotland are made from the Vote of the Department of Agriculture and Fisheries for Scotland, on the advice of the Council. For the financial year which ended on 31st March, 1960, the total of such grants was £832,827 for current expenditure and £182,554 for capital expenditure.

BENEFACTIONS

By the terms of its Charter, the Council is empowered to accept and administer private funds or properties which may be given or bequeathed to it in trust, either for the general purpose of its work or for special objects within its field.

(a) *The Underwood Fund*

This fund, of which the income during 1959–60 was £4,161, has continued to be used by the Council to provide Fellowships or grants for distinguished overseas scientists who wish to visit this country and who are likely, directly or indirectly, to assist the Council's work. The Council is willing to consider applications for Fellowships by, or on behalf of, such scientists, at any time of the year.

Recipients of grants made from the fund during 1959–60 included the following: Dr. R. T. Wedding, of the Department of Plant Biochemistry, University of California, who spent six months at the Council's Unit of Experimental Agronomy as a visiting research worker; Mr. Robert Milford,

of the Cooper Laboratory, Agricultural College, Lawes, Queensland, who spent several months at the Grassland Research Institute; Professor Paul D. Sturkie of the Department of Poultry Husbandry, Rutgers University, New Jersey, who spent a year at the Council's Poultry Research Centre as a visiting research worker.

(b) *The Wain Fund*

The objects of this fund, which was established in 1958, are to facilitate the interchange of scientists between universities in the United Kingdom and overseas; to provide equipment in the universities in the United Kingdom for agricultural research; and to further other schemes of benefit to agricultural research for which the ordinary funds of the Council are not available.

No payments were made from the fund during the financial year 1959-60. The balance carried forward at 31st March, 1960, was £5,326.

FINANCIAL ASSISTANCE FROM OUTSIDE BODIES

The Council gratefully acknowledges the assistance received during the year from the following:—

(1) *W. K. Kellogg Foundation*

The Foundation again provided four Fellowships to enable workers in the agricultural research service to spend study-periods of up to six months in the United States.

(2) *Hatley Foundation*

Grants amounting to \$3,400 were made from funds placed at the disposal of the Council by the Foundation, making it possible for three scientists to visit research institutes while in the United States of America.

(3) *Rockefeller Foundation*

The Foundation made a grant of \$6,900 to the National Vegetable Research Station for the purchase of an ultracentrifuge; to the Scottish Horticultural Research Institute a grant of \$10,000 for a similar purpose; and to the Rowett Research Institute a grant of \$14,750 primarily for the purchase of an automatic amino acid analyser.

(4) *United States Department of Agriculture*

The Department made the following utilisation research grants under United States Public Law 480 from counterpart funds available in the United Kingdom:—

To the National Institute for Research in Dairying: a grant of £31,751 for five years from 7th May, 1959, for the investigation of strains of micro-organisms important in dairy products.

To the Low Temperature Research Station: a grant of £36,300 for five years from 1st January, 1960, for the isolation of enzymes which attack the components of animal connective tissue, to obtain information applicable to the control of freezer damage and improvement in the quality of meat.

(5) *Dr. W. E. Ripper*

A grant of £700 was made by Dr. Ripper of Dow Agrochemicals Ltd., for the appointment of a research assistant to further the work on herbicides which is being undertaken by the Council's Unit of Experimental Agronomy.

NORTHUMBERLAND,

Chairman of the Agricultural Research Council.

E. G. COX,

Secretary of the Council

Cunard Building,

15 Regent Street,

London, S.W.1.

17th *January*, 1961.

SOME ASPECTS OF AGRICULTURAL RESEARCH

ARTIFICIAL INSEMINATION IN PIGS

Pig production still plays a very important part in the economy of many of our farms, although recently there has been some strong competition from abroad. The future prosperity of the pig industry in Great Britain now depends to an ever-increasing extent on the ability of farmers to improve the efficiency of production. The problem of how to reduce costs on the farm and at the same time increase the quality of the pigs which are produced, can be attacked in several ways, but one of the most powerful weapons in the armoury of farmers to-day is the possibility of applying new techniques of husbandry which have been developed by research. It is therefore encouraging that the volume and scope of agricultural research has increased tremendously since the war. Growing co-operation between the scientists and farmer is also enabling new ideas and methods to be put into practice quickly.

For those interested in pig farming or whose livelihood depends upon it, there are many avenues along which research in pigs is being pursued at the present time, and much of the work in this country is supported by the Agricultural Research Council. It is natural enough that a large part of this research has been devoted to problems of feeding and management, because the efficiency with which a pig converts its food into meat, its rate of growth and the final quality of carcase produced, are all of the utmost importance. The control of disease has also received a good deal of attention. One of the most urgent needs to-day, however, is for better pigs on many of our farms. We have a large number of breeds and types which leads to a lack of uniformity in the pig population and this in turn causes difficulties in marketing and lower profits. Although this applies especially to bacon production, it is also true for pork pigs and it is essential, therefore, to produce more animals which conform to a high standard of quality and performance. Improving quality or "grading-up" on a national scale demands the introduction of new methods of breeding and selection, and it is here that the research of geneticists and of those who study the physiology of reproduction can have an important application.

One of the greatest aids to livestock improvement which has been introduced into the practice of animal breeding during recent years is the technique of artificial insemination. By this means, many of the limitations of natural mating may be overcome and the number of offspring from outstanding sires can be greatly increased. Artificial insemination is now extensively used in the dairy industry, but so far, there has been very little application of this technique in pig breeding. Research on artificial insemination of pigs is now in progress, however, and some of the developments which have taken place will be discussed in relation to the practical advantages which might be achieved by the introduction of an artificial insemination service for pigs.

ADVANTAGES OF ARTIFICIAL INSEMINATION

It is possible that specialist breeders with large herds are in a position to develop the most profitable type of animal on their own initiative. On the other hand, the majority of our pig keepers are small commercial producers and they do not have the capital, facilities or experience to undertake the necessary programme of breeding and selection. Under these conditions, there can be no doubt that the best method whereby all pig farmers could take advantage of the most valuable breeding stock in the country would be by using artificial insemination.

An important advance in breeding technique has been made recently by the establishment of progeny testing stations for boars, and it is now possible to select some of the best sires on the merits of the recorded performance of their offspring. By this method it is possible to determine which boars are capable of transmitting their good qualities to future generations. Another method of selection, which is particularly applicable to pigs, is the possibility of measuring performance, such as growth rate and some features of body conformation, in the living animal itself. The development of progeny and performance testing techniques must be regarded as exceedingly valuable contributions to animal breeding, and it is only through the application of these methods by enlightened farmers that we can hope to realise rapid improvements in the quality of livestock in the future. On the other hand, the number of boars which is proved to be of superior breeding quality will always be limited and the impact of progeny testing on the pig industry as a whole will be negligible unless the services from these boars can be increased by the use of artificial insemination.

The possibilities of artificial insemination as a means of livestock improvement have long been recognised. By contrast, it is only within the last few years that we have started to appreciate the fact that the pig is perhaps the most suitable of our domestic animals which could be improved in this way. The special advantage of using artificial insemination in pig breeding is that results could be obtained very quickly because the pig produces large litters of offspring and reaches maturity at an early age. For example, under conditions of natural mating, a boar may be used for breeding about two hundred females during the course of a year, but in practice very few boars are used to anything like this extent. With artificial insemination on the other hand, it should be anticipated that the semen from one boar would be used for inseminating at least one thousand females annually which, in theory, could lead to the production of about ten thousand offspring. If, in addition, it is considered that it takes five or six years to get a progeny test on an animal such as the bull, but that a boar could be tested by the time that he is only eighteen months old, the rapidity with which improvements could be achieved in pigs is indeed striking.

Livestock improvement has been stressed as the first reason for developing artificial insemination service for pigs because it is certainly the most important. In the early stages of development, it is likely that the pig keepers with small herds would derive the greatest benefit. Another good reason for introducing artificial insemination, however, is for the control of certain diseases in pigs, and in this field there could be considerable advantages for the large pedigree breeder as well as for the small farmer. Although at the present time there is

no disease which is known to be spread specifically through the semen or by coitus in pigs, the movement of animals from farm to farm, which is necessitated by natural mating, obviously produces a hazard for the spread of any infectious or contagious disease. This danger is greatly reduced by artificial insemination. As a particular example, it is worth noting that artificial insemination is already assisting some specialised breeders in the attempt to eradicate virus pneumonia from their herds. This step is being taken by a few farmers because there is now a good deal of evidence that virus pneumonia is not only widespread but that it may cause serious reductions in the efficiency of food conversion in fattening pigs. In order to control this disease at the present time, it is necessary to establish disease-free herds, which are isolated from all contact with other herds which might be infected. Complications in the breeding programme may soon arise, however, because there are only a few herds in the country which are proved to be free from virus pneumonia and farmers with closed herds find it difficult to select new breeding stock which is not too closely related to their own. This difficulty may be overcome quite easily by introducing semen from any unrelated boar and using it to inseminate the isolated females.

In view of these two important advantages, for livestock improvement on the one hand and for disease control on the other, there is little doubt that most farmers would welcome the development of an artificial insemination service for pigs. It is necessary, therefore, to consider what progress has been made towards establishing effective practical conditions for starting such a service.

DEVELOPMENT OF ARTIFICIAL INSEMINATION IN FARM ANIMALS

If we look back over the history of the development of artificial insemination in farm animals, it seems a little strange that the pig has been rather neglected for a long time. There is an old story that as long as six hundred years ago the Arabs were using some form of artificial insemination for horse breeding, and it is certainly true that in about 1780 the famous Italian biologist, Spallanzani, made some successful experiments on insemination in dogs. Despite the antiquity of the origin of artificial insemination, however, it was only as recently as the late 1920's that the first fundamental experiments were carried out on artificial insemination in a variety of farm animals, and the possibilities of this technique were being seriously considered. Much of this early work was done in Russia and it was stimulated by the threat of national famine and the necessity for increasing livestock production in that country. At that time, simple methods were being developed for collecting semen from cattle, sheep, horses and pigs and the preliminary results from the artificial insemination of this semen appeared promising and suggested that the technique might be applied successfully in all of these species. Nevertheless, there was very little practical application in other countries until about ten years later and it was only in 1942, for example, that real interest was aroused in Great Britain and the first artificial insemination centre for cattle was established in this country. It is interesting that it was again the threat of food shortage during the crisis of the war which stimulated this development. Since then, a great deal of technical progress has been made, particularly in the field of diluents and storage conditions for bull semen, and the practice of artificial insemination in cattle has grown tremendously. Most of this recent progress has taken place in European countries and the U.S.A. where cattle populations

are dense and communications well developed. Nearly everywhere the emphasis has been almost entirely on cattle, and in Great Britain the success and popularity of the technique is so great that by now over half our dairy cows are bred by artificial insemination and the number is still increasing. Over 90 per cent of cattle are bred by artificial insemination in Denmark and in the U.S.A. the number of cows inseminated each year is estimated to be more than six million. These figures demonstrate quite clearly the magnitude of the revolution which has occurred in the practice of cattle breeding during the last fifteen years. By contrast, developments in other species have been much slower although in some countries, where the conditions are suitable, artificial insemination in sheep is now being practised quite extensively. We have yet to see, however, a situation in which the original promise of the early experiments is fulfilled and artificial insemination is applied on a large scale to the breeding of all our most important farm animals.

As far as artificial insemination in pigs is concerned, there were only a few isolated experiments reported from some countries between 1930 and 1950. The most important of these were carried out in Japan, where some serious attempt was being made to develop artificial insemination in pigs in the years immediately following the end of the war. More recently, there has been a considerable surge of interest in this problem and the volume of research is increasing very rapidly. Exploratory experiments on artificial insemination in pigs were started by the Agricultural Research Council in Cambridge in 1954, and at about the same time some work on similar lines was being developed in France and Norway. To-day, research on artificial insemination in pigs is being pursued in most European countries and also in the U.S.A. In addition to the experiments which are in progress at research centres, there have been numerous attempts to extend the scope of the work by practical application on the farms. In England, most of the field work is being done by several of the established cattle breeding centres, and valuable experience is being gained from the pilot schemes which have now been running for several years.

There is little doubt that the time is approaching when we can look forward to a widespread extension of the technique, but before this can occur there are still some practical and technical problems which must be solved. Some of these problems were discussed at a meeting organised by the European Association for Animal Production which was held recently in France. This meeting was attended by people from most of the countries where work on artificial insemination in pigs is now in progress and from the discussions which took place it is possible to get the most up-to-date picture of the present position of research and development in this field.

ARTIFICIAL INSEMINATION OF PIGS ON FARMS

The most important fact which was brought to light at this meeting was that in nearly all the countries where a field service for inseminating pigs on farms had been started the results were very similar. The proportion of pigs recorded as farrowing after a single insemination with fresh semen varied only between about 40–60 per cent. In Norway, for example, where there are four centres keeping boars, there were 5,000 pigs inseminated during the year 1957–1958 and 50 per cent of the pigs farrowed after one insemination. During the same time, at one of the centres in England where about 2,000 pigs were inseminated, the proportion of pigs farrowing was 42 per cent. Similar figures

were recorded from other countries in Scandinavia, Holland and France. It was the common experience that the results were somewhat better in sows than in gilts, but in both groups of animals it was found that the litter size was similar to that following natural mating. There was one notable exception to this general agreement on field results and that was in the reports from Japan, where it was claimed that out of 30,000 pigs inseminated each year, 70 per cent farrowed after one insemination. At the present time, however, it is rather difficult to assess how the Japanese figures were calculated and it would seem fair to accept the fact that the general success of artificial insemination on farms is only about 50 per cent.

The figure of 50 per cent of pigs farrowing on farms is in sharp contrast to the results which have been reported from research centres. Under the experimental conditions of research centres in this country, a farrowing rate of over 70 per cent can be obtained regularly and this figure is much closer to that which would be expected as a result of natural mating.

The survey of field results emphasises the main problem which is facing those concerned with the practical application of artificial insemination. How can the results on farms be improved so that the method can be applied on a large scale? To attempt an answer to this question, it is necessary to examine more critically some of the techniques which are being employed.

TECHNIQUES OF ARTIFICIAL INSEMINATION

There are four important conditions which must be satisfied if artificial insemination is to be developed on a large scale.

These conditions are:—

- (1) Simple methods must be developed for collecting semen from the male.
- (2) Techniques must be devised for preserving the semen after collection so that it can be used for several days and transported over long distances.
- (3) It must be possible to dilute one ejaculate of semen in such a way as to enable many animals to be inseminated with each collection.
- (4) The results of artificial insemination should be at least as good as those following natural mating.

The research on artificial insemination in pigs can be conveniently considered under these four headings.

SEMEN COLLECTION

There is little difficulty in collecting semen from boars and it seems that these animals are well suited to the type of regime that would be imposed on them at an artificial insemination centre. In practice, the boars are trained to mount a "dummy sow" which is made from a rigid framework and the semen is collected by means of an artificial vagina. The use of a dummy sow illustrates a particular advantage of artificial insemination, because it is possible to continue using boars in this manner for a long time after they may have grown too big and heavy for natural mating. Since semen can be collected regularly two or three times each week, this aspect of the technique is unlikely to be a limiting factor in the extension of artificial insemination.

The semen of the boar differs in several respects from that of the bull or ram. The main differences are that the boar produces a much larger volume of semen, but the concentration of sperm is lower. The bulk of the semen is made up from secretions from the accessory reproductive glands and these secretions contain several chemical constituents, such as inositol and ergothionine, which are not present in bull or ram semen. Under conditions of natural mating, the large volume of semen enters directly into the uterus of the pig and the methods of artificial insemination in cattle and sheep are therefore not applicable to pigs. The composition and physical characteristics of the semen also have an important influence on the behaviour of the sperm during storage.

PRESERVATION OF SEMEN

When semen is collected from the male of any species, the sperm are generally highly active, but they will rapidly exhaust themselves and die if they are kept at body temperature. It is obviously necessary to keep the sperm alive for quite long periods if the semen is to be transported, and the development of suitable conditions for storing bull semen has played a large part in assisting the widespread extension of artificial insemination in cattle.

Many factors influence the time which sperm can survive following collection, but temperature is of outstanding importance. The beneficial effect of cooling can be attributed to the fact that at lower temperatures the motility and metabolic activity of the sperm is reduced and their life-span is thereby increased. If the semen is cooled too rapidly, however, the sperm may be damaged, and it is necessary to protect them by adding special media, such as diluents containing egg yolk or milk. In the routine practice of artificial insemination in cattle, diluted bull semen is cooled to a temperature slightly above freezing point and under these conditions the potential motility of the sperm can be maintained for several weeks and the fertilizing capacity for at least three or four days. More recently, another important advance has been made by the development of methods for storing bull sperm in the frozen state at very low temperatures, and it is now possible to preserve bull semen for many years by the deep-freezing technique.

Unfortunately, the diluents and storage conditions used for bull semen have not proved entirely satisfactory for boar semen and alternative methods have had to be examined. In early experiments on modified techniques for the dilution and cooling of boar semen, some quite promising methods were developed which showed that the sperm could be kept alive for up to six or seven days. An important peculiarity of boar sperm was noted in that they were rather sensitive to cooling and the best temperature for preserving their motility appeared to be about 15° C. By contrast it was soon discovered that, although the sperm could be kept motile for several days, their fertilizing capacity was lost much more rapidly. Most experiments with stored semen showed a marked reduction in the proportion of pigs which became pregnant after insemination with semen that had been stored for even as short a time as one day. This factor has tended to limit the scope of the practical development of artificial insemination in pigs, and at the present time most of the centres are using semen which has not been stored for more than a few hours.

More recently, some rather encouraging results have been obtained by keeping boar semen in the presence of carbon dioxide gas, and preliminary experiments on using such "anaesthetised" sperm suggest that very little

reduction in fertilizing power occurs during the first three or four days of storage. If this work, which has been done mainly in France, is confirmed, then a major obstacle to the development of artificial insemination will have been overcome. On the other hand, there is clearly a need for further work on semen preservation, particularly on methods for freezing boar sperm. So far, no pregnancies have been obtained in pigs inseminated with semen which has been frozen.

DILUTION

The diluting fluids which are employed for the preservation of the sperm are also commonly used for extending the total volume of the semen, so that one ejaculate can be made into many insemination doses. If a standard volume of diluted semen is used for each insemination, it is necessary to determine the extent to which the semen can be diluted and the total number of sperm required for each insemination in order to achieve maximum fertility. In cattle it has been estimated that at least ten million sperm must be inseminated in order to ensure a high conception rate, but since the bull produces about five thousand million sperm in one ejaculate, the semen can obviously be diluted to a large volume and very many cows inseminated from each collection. By contrast, although the boar produces in one ejaculate about ten times as many sperm as the bull, insemination experiments in pigs indicate that about five thousand million sperm should be used for maximum fertility. The vast number of sperm used for each insemination in pigs limits the extent to which the semen can be diluted and means that only about ten pigs can be inseminated with each collection. This factor alone could cause serious complications in the economics of running an artificial insemination service for pigs. Even though it is theoretically possible to inseminate between one and two thousand pigs each year from individual boars, this figure could only be achieved by eliminating all wastage of semen. One of the most important lines of investigation at the present time, therefore, is to improve the technique of insemination with a smaller number of sperm.

RESULTS FROM ARTIFICIAL INSEMINATION

Although artificial insemination under laboratory conditions has given results which are almost as good as those obtained from natural mating, the success of artificial insemination on farms has been much lower. There is little doubt that the main cause of this discrepancy in results is the difficulty of detecting symptoms of "heat" in pigs which are kept on farms and that many inseminations under field conditions are being carried out at the wrong time.

The importance of detecting heat cannot be over emphasised because the correct timing of the insemination during the heat period is essential if the eggs are to be fertilized by the sperm. In sows, the eggs are generally liberated from the ovary at about 30 hours after the beginning of heat, and unless these eggs are fertilized soon after they are liberated they will die. Following insemination, it takes the sperm about six hours to traverse the uterus and ascend the small tubes close to the ovary where fertilization takes place. It can be seen from this programme of events that it is necessary to inseminate the semen within the first 24 hours of heat in order to obtain normal fertilization.

Under laboratory conditions, the onset of heat can be determined quite easily in pigs by testing them with a sterile boar, and insemination can then be

done during the first day. By contrast, on farms where no boars are kept, it is often very difficult to detect the symptoms of heat and pigs may be inseminated either too early or too late. It has been estimated in France that 26 per cent of all the pigs thought to be on heat by the farmers and submitted for artificial insemination were not actually on heat when they were tested with a boar. It is not surprising, therefore, that the results of artificial insemination on farms are low.

The problem of heat diagnosis on farms is not an easy one to attack, but some progress is now being made by training the inseminators and also by obtaining the co-operation of farmers. As both the technicians and the farmers have been gaining more experience in the practical application of artificial insemination in pigs, the results have been steadily improving.

A survey of quite a large number of inseminations undertaken in the field has shown that the results are considerably better when pigs stand well during the insemination than if they are restless. This is probably due to the fact that the pigs which stand well are most likely to be properly on heat, but it also gives a much greater chance of effecting a good insemination. The importance of inseminating a large number of sperm into the pig's uterus has already been emphasised and restlessness may cause large quantities of the semen to be wasted. Much attention at artificial insemination centres has been devoted to devising improved types of insemination equipment, in order to reduce the waste of semen and considerable progress has now been made along these lines.

To sum up the present position of artificial insemination in pigs, it is clear that the most urgent need to-day is to improve the results on farms. The rather low conception rate has been the greatest limiting factor to the extension of the technique during recent years. The success of artificial insemination on farms depends to a large extent on better methods of heat diagnosis. In the laboratory, the main problems to be solved are the preservation of the semen and increasing the chances of fertilization with a small number of sperm.

Despite the difficulties which have been encountered, there is a good indication that artificial insemination in pigs will soon become more practicable and that it will develop into a valuable aid for livestock improvement in the future.

HYBRID VIGOUR AND POULTRY BREEDING

The introduction and exploitation of hybrid* poultry derives directly from the success of hybrid maize in the U.S.A. This maize was first marketed in quantity by Henry Wallace in 1926, and it was created by the empirical genetic

* Progeny of matings between genetically different parents are hybrids since their gene pairs are heterozygous or unlike (i.e. are A_1A_2 ; B_1B_2 , etc.). However, in the animal breeding literature, the term hybrid is commonly employed in a more specific sense and means the progeny of a cross between inbred, more or less homozygous parents (i.e. between A_1A_1 ; B_1B_1 , etc. and A_2A_2 ; B_2B_2 , etc.) which have been chosen because their offspring display a high level of vigour compared with the better parent or with the average of the parents. Such crosses may be simple or complex: two-way or single cross (i.e. line W by line X giving WX progeny); three-way cross (i.e. WX by Y), or four-way or double cross (i.e. WX by YZ). If the crosses are made from inbred lines within a breed they are called incrosses, if they are crosses of inbred lines of different breeds they are designated "incrossbred." "Breed crosses" are usually made using non-inbred stock, but they sometimes involve mating particular, selected strains of the two breeds. "Strain crosses" of non-inbred stock within a breed are also employed. All possible combinations of these procedures for exploiting the hybrid vigour associated with genetic heterozygosity appear to be in use in Britain today, and some four-way crosses apparently involve inbred, strain and breed crosses to this end.

technique of crossing four inbred lines which combined well, first as separate, two-way crosses and then by mating these to produce the double cross sold on the market. In 1942, the same organisation introduced "Hi-line" chicks, bred in the same way, and sold them through their agencies previously established for the dissemination of seed corn. By 1940, hybrid corn made up about 80 per cent of the American crop; and hybrid fowls must account for about this proportion of the American laying flocks in 1960. In America, too, single crosses between breeds constituted practically the only type of fowl used for meat (broilers) as early as 1942, and they are rapidly assuming this position in the British market¹. This change to hybrids has occurred precisely during the period when geneticists have been refining their methods for the efficient exploitation of "pure" strain selection. That is, successful practice has depended on a trial and error procedure based on the complex testing of more-or-less inbred lines in combination, and not on the developments of quantitative genetics which have been the major concern of poultry geneticists during the last two decades². As a result, the number of relevant published researches on hybrid poultry is small. There has been no compensating flow of information from the commercial organisations, whose data tend to remain trade secrets.

The development of a successful hybrid involves a considerable capital investment. Strains have to be found or developed; they must be "fixed" or inbred to the equivalent of four or more brother-sister matings; they have to be crossed together in all likely combinations; and once a successful grouping is found they have to be multiplied for sale. In all, any one particular double cross hybrid may take 8-10 years to market, and many years of work will be lost in unsuccessful trials. For example, 20 strains can be mated to give 380 two-way crosses and 116, 280 four-way crosses, and only a small proportion of these are likely to be worthwhile. Indeed, one has merely to note these figures to see that only small numbers of strains can be tested, and that shortcut procedures must be adopted in choosing the hybrids actually sold. One consequence of this is that hybrids are not necessarily superior to the best pure strains, as random samples tests clearly show³; and they are generally more costly to produce. Their merit is that they are usually in the top rank, and *they can be mass-produced and re-produced* from one year to the next. Because hybrids do not breed true, the user must return annually for his replacement stock thus ensuring a regular market. Further, by suitable choice of the parent lines the characteristics of the final product can be tailored to some extent to meet economic requirements, whereas with "pure" breeds this cannot be done so readily and the buyer has to pick from among the selection of pure bred stock available to him. These "industrial" characteristics of hybrid production have generally been ignored by reviewers⁴ but they are precisely the ones which have led to the successful exploitation of this, the first mass-produced animal.

Two further points must be noted. Although the initial investment in developing "hybrids" is high, the multiplication of the stock can be sub-contracted to others. Only small numbers of the inbred parent stock of low production merit have to be held (about 2,500 birds expanded by the double-cross technique could supply the 35 million or so replacements required annually in British laying flocks) while their single-cross progeny (WX and YZ) can be passed to multipliers who produce the double-cross hybrid eggs for

hatching. This hierarchical structure depends on the fact that the single-cross progeny do not breed true, and can therefore be passed safely from the direct control of the originator. So a great flexibility of output in relation to market needs is possible, and this cannot be so easily achieved with pure breeding. Secondly, more easily developed three-way ($AB \times C$) and two-way ($A \times B$) hybrids are also sold, but there are no data to show how important they are commercially, except in the breeding of broilers.

This outline allows us to formulate the problems relevant to the industry and to set aside some studies which, while of genetical interest, are not of primary practical importance. Clearly, the central problems of producing hybrids relate to the criteria required for preparing the parent lines; the qualities of the starting strains, the extent of inbreeding prior to testing in crosses, the amount and kind of selection practised during inbreeding; and to the accumulation of information concerning their behaviour in crosses which will allow prediction of hybrid performance. It is a measure of the inadequacy of poultry research in this field that there are no published data giving the concurrent performances of parent lines and their two-way and four-way crosses which would permit even some analysis of these problems. This deficiency should shortly be made good⁵.

INBREEDING

The purpose of inbreeding is to make the parent lines more or less homozygous (i.e. having pairs of identical genes) and so to fix their characteristics that they can be employed for making consistent crosses for a number of years. All experiments with animals have shown that such homozygosity is difficult to achieve, and poultry are no exception. The very first inbreeding experiments resulted in the rapid extinction of the brother-sister mated lines, primarily as a result of lowered hatchability. However, if inbreeding is accompanied by selection for high hatchability (and large family size) homozygosity may be increased to about four-fifths of the calculated maximum without drastic consequences to production traits as a whole⁶. But as experiments have been done with very different initial strains and breeds and under very different scales of operation, no practical rules for inbreeding with selection can be deduced from published reports. Some of the relevant problems have been studied theoretically⁷ but only with respect to single gene pairs. In so far as one can generalise from this work, it seems likely that slow inbreeding will permit the retention of localised heterozygosity (i.e. having pairs of unlike genes) on the chromosomes (and, therefore, high hatchability etc., in so far as these depend on heterozygosity) whereas close inbreeding will not⁸. However, the situation for traits like egg production controlled by many genes, presumably scattered throughout the chromosome complement, is not likely to be as simple as this, and one experiment⁶ shows that rate of inbreeding is not of great consequence if selection is also practised.

With animals, inbreeding presents a practical difficulty because of its cost, and because improvement of a "hybrid" necessarily implies the eventual replacement of one or more of the parent lines by others. For economic reasons, only so much effort can be expended on any line or group of lines, and this raises the question: what is the best starting material and how much inbreeding need be done before testing the line in cross combinations? There is some evidence from experimental animals that gains made by selection prior

to inbreeding are not lost in crosses, and that poor initial stock never (or rarely) give good hybrids⁹. Further, selection during inbreeding may result in cryptic gains which are revealed only in the more favourable genetic environment of the hybrid¹⁰. For the practical reasons just mentioned, this usually means that parent lines are started from strains known to have a good performance and that inbreeding is carried only to the level of halving the initial heterozygosity before testing cross-performance. Other considerations also enter into the selection of lines since traits such as egg weight and body size are not greatly depressed by inbreeding (unlike hatchability, growth rate, age at maturity and viability) and behave additively, or nearly so, in crosses. The final hybrid can be "tailored" for these characteristics, and those determined by single mendelian genes, in much the same way as maize has been fashioned for height, lodging qualities and rust resistance, etc., by plant breeders during the last decade. And this aspect of "hybrid" breeding, since it leads to the development of a bird of optimum size, laying the economically desirable weight of egg, is a major reason for the increased use of hybrids.

The practical limit set to the number of inbred lines of poultry which can be developed restricts the full exploitation of the hybrid technique. No data have yet come forward which can be used to characterise particular inbred lines and indicate the properties which they transmit in crosses, similar to the listings available for maize. Much work would be saved if some co-operative effort were made to do this and to share experience. Further inbreeding inevitably leads to the impoverishment of the total stock of genes in the overall poultry population by elimination of unsatisfactory lines, and the only way to avoid this loss is to create many inbred lines⁷ and to spread the cost of maintaining them.

CROSSING

The cross performance of an inbred line is frequently stated in terms of its general and specific combining abilities, the former being measured as the average increase of vigour in crosses with a number of other lines and the latter by its exceptional performance (nicking) with a particular line. Neither concept seems especially useful to the development of four-way crosses since genetic segregation occurs in the four-way cross, and "specific" combinations of genes are consequently lost. In any event, there is no satisfactory evidence that specific combining ability is important even in two-way crosses of poultry although this is the common, practical assumption. Measurement of general combining ability partly depends on the strains used as "testers" and it would seem more reasonable to assess cross performance by making all possible matings among a number of inbred lines rather than depend on an incomplete range of "tester lines". Top-crossing (mating males of one line to females of other lines or strains) has been tried with poultry, since it has had some success for plants, but published results do not suggest that it has much promise as means of measuring cross-performance¹¹. These tests also pay too little regard to the fact that the four-way cross is usually a cross between breeds, in which maternal and sex-linked effects are often important.

(a) *Incrosses and Incrossbreds*

The simplest situation in which to study the effects of crossing is by using lines derived from the same stock since some of the differences found between

breeds are then eliminated. Examination of Brown Leghorn incrosses shows that the egg production of the hybrids is determined by the average production of their parents and an additional hybrid gain, which is more or less constant over a wide range of mid-parent values¹². Incrosses mature earlier than the mean of their parents, but there are reciprocal differences in this respect, some of which may be related to egg size. As might be expected, hybrids of early maturing parents do not show as great an advancement of maturity as those from late maturing parents. March egg size tends to be identical with the average of the parents, except that crosses of small egg lines show a slight degree of hybrid vigour in this trait. There is no clear relation between egg size and egg number except that the lines producing the largest eggs also lay fewest. These studies require confirmation with other breeds, but they agree with the few reports currently available.

Data on crosses between inbred lines of different breeds are far from adequate, and while such crosses might be expected to demonstrate more hybrid vigour, because of their greater genetic diversity, this is far from certain¹³. When the crosses are between heavy and light breeds, broodiness is common, and as its extent is partly determined by sex-linked genes reciprocal crosses differ in the degree to which they show this defect¹⁴. Hatchability is improved from both incross and incrossbred matings and this tends to make economic the multiplication of such crosses for double-cross hybrid production.

(b) *Four-way crosses*

Because it is possible to make very large numbers of four-way hybrids from small populations of inbred lines, the main problem is that of predicting the characteristics of the hybrids from the lines and from the two-way crosses. As already noted, this can be done approximately for such traits as March egg weight, broodiness etc., but attempts to devise adequate rules for estimating age at first egg, weight at maturity, and egg production (i.e. the characters which display hybrid vigour) have been unsuccessful¹⁵. This is surprising in view of the success attained with maize since specific combining ability apparently plays a negligible role in determining hybrid performance. Certainly, it is partly a consequence of maternal and sex-linked effects, but it is also due to the relatively large influence of environmental differences on performance. In short, differences of husbandry and the varied response of the genotypes (parent, two-way and four-way crosses) to these differences, tend to mask any regularity in the behaviour of the small samples which have been studied experimentally. However, it would be too pessimistic to say that there is "no clue as to how the more successful crosses may be predicted: only by trial can this be determined"¹⁶ even though practice is still largely a matter of trial and error.

Lacking adequate means of prediction attempts are being made to use physiological measures as ancillary guides to breeding: blood typing is the technique currently most in favour. In effect, this is used to identify and select parent lines which carry particular blood group genes and to use only heterozygous combinations of the genes which have been found to do well. Crosses which would not give these combinations are not made, and a considerable amount of labour in testing their performance is saved. Unfortunately, published data are very incomplete¹⁷ and it is difficult to judge if this method is of real value.

(c) *Breed crosses*

The procedure of crossing different breeds of fowl goes back to antiquity, when such "hybrids" were noted for their general vigour. The more recent popularity of breed crosses in Britain seems to derive from the advantages of crossing sex-linked plumage types which allows the early identification and elimination of males not required in egg production flocks. The breed cross probably had its greatest vogue during the post-1945 expansion of the industry when about three-quarters of the laying birds were of this type. Currently, it is being replaced by the hybrid. None the less, there is ample evidence that crosses of non-inbred groups of different breeds may perform better than either of their parents¹⁸, although they are frequently prone to broodiness and sometimes to mortality as adults. Since no two breed crosses are from the same strains, and differences are known to exist in the crossing abilities of strains, there has been no detailed genetical analysis of breed crosses. It should be noted, however, that some crosses developed by particular breeders are of considerable merit and deserve detailed study.

In so far as breed crosses depend on heterozygosity for their extra vigour, procedures can be developed for holding this heterozygosity at a reasonable level without the expense of keeping the flock in two large, but separate, parts. One system is "criss-crossing" in which males of alternate breeds are mated to the cross-bred population in successive generations¹⁹, so that the constitution of the cross-bred population alternates between $\frac{1}{2}A, \frac{1}{2}B$ and $\frac{2}{3}A, \frac{1}{3}B$ from year to year. Such a population apparently continues to be superior to the breeds from which it is derived¹⁹. The extension of this, rotational crossing, in which the hybrid progeny population is successively mated to males of three different breeds during three years, and the cycle repeated indefinitely does not appear to have been tested with fowls although it has had some success with pigs²⁰. Both systems have the advantage that relatively small numbers of males have to be carried along with the crossbred population.

Broilers are commonly breed crosses which take advantage of the faster early growth found among hybrids. But this rapid growth and, hence efficient food utilisation, is only one consideration: good conformation, early and light (or white) feathering and good egg production are others. The practice is therefore to use one breed (or more frequently a two-way cross) which lays well as the female parent so that chick costs are kept down, and to improve conformation by introducing this from the male. Both parent strains can be improved and adapted to market requirements by ordinary selection procedures. What is not clear is how far hybrid vigour determines the success of such crosses in ways different from those already considered for laying birds (i.e. by improvement of hatchability and viability etc.). It is commonly assumed to contribute to the notable food conversion efficiency of broilers, but it is not certain that this is more than a consequence of rapid early growth and not due to improved metabolic efficiency as such, although tests with experimental animals suggest that hybrids should have this advantage.

Selection for hybrid performance

This topic has recently been reviewed²² and the conclusion drawn that selection for hybrid vigour will remain very much a hit or miss affair until the genetic mechanisms involved are more fully explored. It might be added that many physiological processes will also have to be understood²⁰.

The two most popular procedures are "recurrent selection" in which one line is selected by breeding from the parents which cross best with a particular group (or with an inbred line) and "reciprocal recurrent selection" in which parents from two groups are each selected on the basis of their reciprocal cross performance. In essence, both are techniques for exploiting specific combining ability; that is, for selecting particular constellations of genes which give the best end result when they are present in a heterozygous condition. Clearly, the outcome of such a process will depend on whether or not specific combining ability is important and if the desired genes are to be found in the initial populations (which cannot be foreseen) and on their action in the homozygous state (which might be highly detrimental). Practically, both procedures are likely to take many generations to fulfil their objectives and they do not carry any *a priori* guarantee that the parent lines so developed will themselves be of great economic worth. There is no satisfactory report showing that either technique works for plants (for which they were first suggested) and tests with experimental animals have been equivocal⁹.

CONCLUSION

For the economic reasons noted, it seems probable that in Britain the four-way cross will rapidly become the dominant type of laying bird and the three-way cross the main broiler fowl. If the American example can be taken as a precedent, this is likely to occur without adding much to our understanding of the phenomenon of hybrid vigour which is being exploited and, as seems to be happening with maize, progress may eventually slow down to a point where sales apparently depend as much on advertising as on intrinsic genetic merit. Since only small numbers of parent lines of animals can be developed and tested (unlike plants) chance must inevitably play some part in the successful creation of any particular meritorious four-way cross. So no one breeder is likely to be permanently ahead of the others. On the other hand, control of environment and nutrition (impossible with many plants) should allow the more accurate comparison of hybrids, permit a more rational choice among them and allow a better assessment of their role in the whole poultry population.

¹ COLES, R. 1960. *Development of the poultry industry in England and Wales, 1945-1959*. London. Poultry World Ltd.

² LERNER, I. M. 1958. *The genetic basis of selection*. New York. John Wiley & Sons, Inc.

³ ANON. 1960. *Report No. 21, Council of American Official Poultry Tests, 1958-1959*. U.S.D.A.

⁴ WARREN, D. C. 1958. *Poult. Sci.*, **37**, 3-20.

⁵ ANON. 1960. *Report of the Agricultural Research Council for the year 1958-1959*. London. H.M.S.O.

⁶ WATERS, N. F. and LAMBERT, W. V. 1936. *Research Bulletin No. 202*. Iowa State College of Agriculture.

⁷ FISHER, R. A. 1949. *The theory of inbreeding*. Edinburgh. Oliver & Boyd, Ltd.

⁸ REEVE, E. C. R. and GOWER, J. C. 1960. *Biomet. Gen.*, 24-34. London. Pergamon Press.

⁹ BELL, A. E. and MOORE, C. H. 1958. *Proc. X Internat. Congr. Genet.*, **2**, 20-21.

¹⁰ SCHULTZ, F. T. 1953. *Heredity*, **1**, 1-21.

¹¹ NORDSKOG, A. W., SMITH, L. T. and PHILLIPS, R. E. 1959. *Poult. Sci.*, **38**, 1372-1380.

¹² BLYTH, J. S. S. and SANG, J. H. 1960. *Genetic Res.*, **1** (in press).

¹³ GLAZENER, E. W., COMSTOCK, R. E., BLOW, W. L., DEARSTYNE, R. S. and BOSTIAN, C. H. 1952. *Poult. Sci.*, **31**, 1078-1083.

¹⁴ HUTT, F. B. 1949. *Genetics of the fowl*. New York. McGraw-Hill Inc.

¹⁵ HILL, J. F. and NORDSKOG, A. W. 1958. *Poult. Sci.*, **37**, 1159-1169.

- ¹⁶ PEASE, M. 1954. Sect. papers, 10th World's Poultry Congress, 45-49.
- ¹⁷ BRILES, W. E. 1956. *Poult. Sci.*, **35**, 1134-1135.
- ¹⁸ NORDSKOG, A. W. and GHOSTLEY, F. J. 1954. *Poult. Sci.*, **33**, 704-715.
- ¹⁹ SKALLER, F. 1954. Sect. papers, 10th World's Poultry Congress, 59-64.
- ²⁰ SANG, J. H. 1956. *Animal Breeding Abstracts*, **24**, 1-6.
- ²¹ ROBERTSON, F. W. 1959. *Genetics*, **44**, 1113-1130.
- ²² BOWMAN, J. C. 1959. *Animal Breeding Abstracts*, **27**, 261-273.

THE TRANSFERENCE OF IMMUNITY FROM MOTHER TO OFFSPRING

Mammals normally have considerable powers of resistance to the diseases to which they are liable. Much of this resistance is due to the presence in the blood of antibodies. When certain foreign substances, such as the infective agents of protozoan, bacterial or virus diseases, enter the body they act as antigens which stimulate the animal to produce antibodies to them. These antibodies are very specific and react only with the particular kind of antigen which stimulated their production. An animal during its normal life is exposed continually to germs of many kinds which enter the body through the mucous surfaces of the respiratory, digestive and urinogenital tracts and through the skin. Although these organisms may not be in a state, or in sufficient quantity, to produce any other apparent effect they can start the process of antibody production. Sometimes the organisms will establish themselves and cause disease but more often they will produce no apparent effect, being in insufficient quantity or in an uninfected state. Yet whether the animal develops the disease and recovers or shows no ill effects, the process of antibody formation is likely to have been started. If so, a subsequent exposure to the same antigen after an interval is followed normally by a copious production of antibody, which soon appears in the blood. Such an animal is said to be actively immune to that particular antigen and even very heavy subsequent infections can be resisted. It will continue to produce the antibody for a long time or even throughout life, though in gradually declining quantity unless it is exposed to the antigen again. Thus the animal during its life builds up powers of resistance to each of the antigens to which it has been exposed and the total equipment of antibodies reflects the sum of its past antigenic experiences.

The newly-born animal has little capacity to make antibodies in response to antigenic stimuli and this capacity develops gradually over a period of weeks or months. Even if it possessed this power, it could provide little protection against disease since prenatal life within the uterus is sheltered from most antigenic stimuli. The new-born animal, therefore, lacks active immunity and would be deficient in circulating antibodies were it not endowed passively with those of its mother. Antibodies can be transferred from the circulation of the individual in which they have been actively produced to that of another individual which has not learned to make them and so can confer on the recipient "passive immunity." This passive immunity is effective and immediate, but it is not permanent, lasting only so long as the antibodies remain in the circulation, a matter of weeks or at most a few months, because the recipient does not replace them. The young mammal receives the maternal antibodies either before or after birth, or both, according to the species¹; ². Calves, lambs, kids, piglets and foals are born without any passive immunity and derive their maternal antibodies from the first milk—"colostrum"—during their first few hours of independent life³. The maternal antibodies secreted in the colostrum

are transmitted rapidly to the circulation of the new-born animal across the walls of the digestive tract. The young animal's capacity to absorb the antibodies intact from the gut contents is transitory, lasting only a few hours. If colostrum is not fed to them until 48 hours after birth, it is too late, because the antibodies are then digested, instead of being transmitted, and only their degradation products reach the circulation. The new-born calf, for example, depends for its passive immunity on being fed with the antibody-rich colostrum within a few hours of birth, and to deprive it of this is to rob it of much of its powers to resist infection. At this time antibodies are transmitted so rapidly from the gut to the circulation and are in such high concentration in the colostrum that they attain a concentration in the blood of the calf equalling or exceeding that in the blood of the mother within a few hours. Unfortunately no small laboratory animals that can be used conveniently for experimental study of the process behave exactly like farm animals in all these respects. Human infants and the young of monkeys, rabbits and guinea-pigs are born with their full equipment of passive immunity, which is not augmented appreciably after birth². The maternal antibodies have been transmitted to them while still in the uterus across the membranes which enclose the foetus and constitute the maternal/foetal barrier. Thus, the new-born infant already has its whole quota of maternal antibodies and does not depend for them on its mother's milk, however important this may be in other respects.

Rats, mice and dogs are intermediate between these two groups of animals in that the young gain their passive immunity from the mother partly before birth, across the foetal membranes, but mainly after birth by way of the milk and the digestive tract. The puppy absorbs antibodies from the milk for about ten days but the young mouse and the young rat continue to do so almost throughout the nursing period, for 16 and 20 days respectively. Rats and mice then stop absorbing antibodies from the milk suddenly, although the antibodies continue to be secreted in the milk. Despite these differences from farm animals, rats and mice provide the most convenient animals in which to study experimentally the transmission of immunity by way of the milk.

Appreciation of the practical significance of the transference of immunity from mother to young for animal husbandry and for medicine involves some knowledge of the nature of antigens and antibodies. To act as an antigen in the body and stimulate the production of antibodies a substance must as a rule be foreign to the body and must be associated with a protein. With some special exceptions, the body's own components cannot act as antigens since the body recognises them as "self." Protein components of other organisms, even of other individuals of the same species, may act as antigens, whether they be soluble proteins or parts of the bodies of cells, such as blood corpuscles or bacteria or virus particles. Thus the red blood corpuscles of another kind of animal or even of another individual of the same kind are highly antigenic as a rule. The antibodies produced in response to the stimulus of an antigen are molecules of globular protein which, when blood clots, remain in solution in the fluid serum. These antibody globulins are very large, with molecular weights of around 160,000 or more. The peculiar property of an antibody which distinguishes it from the other molecules of serum globulin is its capacity to attach itself to the particular kind of antigen which stimulated its production and to no other; it is extraordinarily specific in its action. The attachment of the

antibody leads to the rapid destruction of the antigen, be it red blood corpuscle, bacterium, virus or soluble protein, and to its rapid elimination from the body. It is not necessary for the present purpose to consider the reaction of antibody and antigen further than to say that it is believed to be due to the adaptation of one or more regions on the surface of the antibody molecule to fit a surface feature of the antigen, as a casting fits its mould.

Since the survival of every young mammal depends on its powers of resistance to disease, knowledge of the processes by which it is equipped to do so is obviously of first importance. Another weighty reason why this knowledge is of practical importance is that certain diseases, both of man and of domestic animals, result directly from the transfer of maternal antibodies to the young. This occurs when the mother produces antibodies to antigens which the young possess through inheritance from the father, but which the mother does not herself possess. In these special circumstances the maternal antibodies, on reaching the circulation of the offspring, may react with these antigens and if they are in the blood-cells destroy them, causing haemolytic disease, which may be fatal. Examples of this disease are well known, both in domestic animals and in man.

Haemolytic disease occurs naturally in both mules⁴ and thoroughbred horses⁵. The disease has been known to mule breeders for a long time, though its cause has been understood only since 1947. Mares used for breeding mules are liable to become immunised to the donkey red-blood-cell antigens, which the offspring inherit from the father but which the mother does not possess. These antigens reach the mother from the foetus in the uterus and she responds by producing antibodies in her circulation which are secreted in her colostrum. When this occurs the foal is born healthy but, if it feeds on its mother's colostrum, it develops the disease rapidly and may die. This is caused by the maternal anti-donkey antibodies in the colostrum being transmitted to the circulation of the mule foal where they react with the red-blood-corpuscles, destroying them and causing anaemia and jaundice. The foal can be saved, since it is born healthy, by preventing it from suckling the mother for the first two days, so that it does not receive her antibodies. Once a mare has developed the antibodies she cannot be used for breeding mules, unless they are fostered at birth, since she will always transmit the anti-donkey antibodies in her colostrum, but she can be used for breeding horses, on which the antibodies have no effect. A similar disease occurs in thoroughbreds. It is due to the foal's inheriting from the sire red-blood-cell antigens which the mare lacks. As with the disease in mules, the foals are born healthy and can be saved by fostering from birth. Once immunised to the red-blood-cell antigens of a particular sire the mare's colostrum will always produce jaundice in the foals of that sire, but foals by another sire, which lacks the particular red-blood-cell antigen to which she has become immune, can suckle her safely. That the mare has become immune can be shown readily by mixing, on a white tile, drops of her serum with drops of blood from the foal and from the sire; if antibodies are present in her serum the red blood corpuscles of both the foal and the sire will become coated with antibody and agglutinate or stick together in clumps, producing a characteristic change in the appearance of the drop on the tile.

A precisely similar disease occurs rarely in piglets. They are born healthy but develop jaundice soon after the first feed of colostrum. This is due, as in

horses, to the transmission in the colostrum of maternal antibodies to red-blood-cell antigens which the affected young possess, having inherited them from the father, but which the mother herself happens not to possess. Whereas in horses the mother becomes immunised naturally by foetal antigens entering her system during pregnancy, the pig appears not to be immunised naturally by pregnancy but to produce antibodies in response to the red-blood-cell antigens that are contained in a vaccine for swine fever⁶, which are occasionally identical with particular antigens in the piglet.

Haemolytic disease in man is comparable with that in horses and pigs in that the mother becomes immunised to red-blood-cell antigens which the offspring has inherited from the father and which she does not possess. She may become immunised naturally during gestation of an incompatible foetus, through foetal antigens reaching her circulation, probably by leakage of foetal blood through the placenta, or artificially at any time during her life by transfusion with incompatible blood. Antibodies, once formed, may be transmitted across the placenta to any subsequent foetus she may bear, and if this foetus has inherited the corresponding antigens on its red blood corpuscles these will be destroyed as a rule. The affected human foetus may die in the uterus and be stillborn, or it may be born alive, suffering from haemolytic disease to any degree from the trivial to the fatal. The antigen most commonly responsible is D, belonging to the rhesus blood group system, and hence the disease is popularly known as rhesus disease. Occasionally other antigens of the rhesus, ABO, or certain other blood group systems, may be responsible. These are inherited in a simple mendelian manner and when the disease occurs the foetal antigen responsible is invariably inherited from the father and absent in the mother. Increase in knowledge of the causes of this disease in man, since its discovery⁷ in 1939, has made it possible to reduce its occurrence by avoiding incompatible blood transfusions to women of potential reproductive age, to predict the possibility or probability of its occurrence by blood grouping both parents and testing the mother for antibody production, and in many cases to alleviate the severity of the disease in affected new-born infants. The disease is still, however, an important factor in foetal and neo-natal mortality and in congenital injury and much remains to be learnt about it.

Although haemolytic disease is not known to occur naturally in laboratory animals it can be produced in them experimentally. For example, haemolytic disease can be produced in the new-born mouse by giving it by mouth a few drops of an anti-mouse red-blood-cell serum prepared in a rabbit. It has been possible in this way to study the location and kind of damage caused by the antibodies and to understand the significance of the various symptoms observed⁸. It is apparent that the transference of immunity from mother to young raises a great many problems requiring solution. First, it is necessary to know the precise route of transference of the antibodies if the mechanism of transmission is to be studied experimentally. In those animals which get their antibodies after birth from milk, transmission occurs across the wall of the digestive tract, mainly of the small intestine. The route of transmission before birth is by no means so obvious and is difficult to determine, since it involves experiments on the foetus in the uterus². It has been possible to demonstrate that in the pregnant rabbit the antibodies are secreted into the uterine cavity and are absorbed from there across the foetal yolk-sac wall into the foetal circulation.

They do not pass directly from the maternal circulation across the placental membrane to the foetal circulation, although it was expected that they might because this is the route of exchange of small molecules such as oxygen, carbon dioxide, etc., and the placental membrane is specially adapted to bring the maternal and foetal circulations into as close proximity as is possible without mixing of the bloods. It has been confirmed subsequently that transmission is by way of the yolk-sac in the guinea-pig, and also, in so far as concerns that part which occurs before birth, in the rat. It is interesting that this route corresponds to that in birds, where the maternal antibodies are secreted into the yolk of the egg while still in the ovary and are absorbed from the yolk at the end of incubation by the embryonic yolk-sac of the chick, which has by then grown around and contained the yolk. The yolk-sac in the chick, as its name implies, is a yolk-containing and an absorbent organ. Mammals have scarcely any yolk in their eggs and in many mammalian embryos the yolk-sac is vestigial. But in the embryos of rabbits, guinea-pigs, rats and mice a large yolk-sac is present, though one wall is incomplete and there is no yolk, and it retains its primitive absorptive function in taking up antibodies from the uterine cavity. Man and the monkeys have only a vestigial yolk-sac to which the function of transmission of immunity can not be ascribed, so transmission in these must occur by some other route. Recently some experimental evidence has been obtained that it occurs across the placental membrane in the monkey⁹, unlike the rabbit, and the inference is that it does so also in man in whom the structure and functions of the foetal membranes are so similar.

The yolk-sac of the foetal rabbit and the gut of the suckling rat provide two very convenient living membranes through which the transport of antibody globulins and other proteins can be studied. The foetal yolk-sac can be exposed to chosen proteins in solution by injecting them into the cavity of the pregnant uterus—a fairly simple procedure—and the young rat can be fed even more easily through a very small stomach tube. The proteins, after crossing the membrane, can be recovered in the blood of the young animal and, if suitably labelled in advance, they can be identified and measured.

The choice of appropriate methods of labelling protein molecules, so that they can be distinguished subsequently, involves technically difficult problems and no known method is ideal. Three principal methods are available and can be used singly or in combination. The specific biological activity of a protein, such as an antibody, an enzyme or a hormone, can be used as a means of recognition by its reaction with antigen, substrate or target organ respectively. In practice, the most convenient method is to use an antibody prepared in an animal other than the one in which it is to be used as a labelled protein. Secondly, the same principle can be employed inversely by using the chosen protein as an antigen. It is injected into an animal which, in due course, produces antibodies which react specifically with it. The immune serum of this animal can then be used as a reagent to identify the antigen in samples of the body fluids of other animals. Thirdly, radioactive isotopes can be used as labels on protein molecules, either by being built into them by a living organism which synthesises the protein after being fed with the isotope in an appropriate form, or by being attached chemically in a test-tube; one of the most useful isotopes for the latter purpose is iodine (¹³¹I), which can be tagged on to a protein readily. All these methods are exceedingly sensitive so that very small

traces of the labelled protein can be detected by their use. Each method has its own technical limitations but, in certain circumstances, it is possible to use all three labels on one protein simultaneously and so to check the one against the other.

Proteins in solution are absorbed rapidly by the cells of the yolk-sac of the foetal rabbit or the intestinal lining of the suckling rat. It has been shown with the aid of the electron microscope that the cells of both of these membranes are clothed on their exposed surfaces with a pile, like velvet, composed of minute processes and that the solution of protein is absorbed as droplets through minute tubules opening between the bases of these¹⁰. Uptake does not appear to discriminate between different kinds of protein in the same solution. Most of the protein entering the cells is broken down by them and transmitted to the circulation only as degradation products of small molecular size¹¹. Some of the protein is not degraded in this way and is transmitted by the cells to the circulation apparently unaltered; it is this fraction which includes and accounts for the transmission of the maternal antibodies as such. The transmission of intact protein is highly selective, not indiscriminate, and the proportion of a given protein that reaches the circulation intact depends upon its precise nature and even on the species of animal in which it has been formed. In the rat, for example, the gamma-globulin from rat serum is transmitted more readily than the albumin in the serum, though this is transmitted in small quantities. Since the gamma-globulin molecules are much larger than those of the albumin this is remarkable. Apparently, selection occurs within the cells; it is not a simple sieving according to size but depends on more subtle qualities. It is generally accepted that antibody activity depends on the surface configuration of the gamma-globulin molecule and is destroyed readily by distortion of the molecule, yet antibody is transmitted without loss of activity. All antibodies, however, are not transmitted equally readily. Two kinds of antibodies, formed to different antigens in one species of animal and possibly in different fractions of the serum proteins, may be transmitted at very different rates; as may even two different antibodies from the same individual serum¹². Rabbit gamma-globulin molecules have been broken up into two or three large pieces, by being digested with enzymes in a test-tube under carefully controlled conditions, and these different pieces have been separated by physical means¹³. By isotopically labelling these sub-molecular fractions and comparing their transmission in the rabbit with that of whole molecules of gamma-globulin it has been shown that the sub-molecular pieces of one fraction are transmitted nearly as readily as the whole molecules, whereas those of another fraction are transmitted only one-tenth as readily¹⁴. Evidently selection also operates as between the different pieces into which a molecule of gamma-globulin can be broken and none of the pieces is transmitted more readily than the whole molecule, despite their smaller size.

The transmission of antibody globulin appears to be selective in man, as well as in the rabbit, guinea-pig, rat and mouse but, as yet, experiments designed for the purpose have failed to show any selection of serum protein by the intestine of the new-born lamb or calf during the brief period when transmission occurs¹⁵.

The cellular processes involved in the uptake, selective transmission and secretion of serum proteins are of fundamental interest and wide biological

significance. The foetal yolk-sac of the rabbit and the intestine of the suckling rat provide exceptionally favourable opportunities for studying these processes on a scale that is well within the sensitivity of the techniques available. These opportunities hold promise of throwing some light on the manner in which protein specificity is related to intracellular structure and function. The rate of progress may depend largely on advances in knowledge of the molecular structure of proteins, a branch of chemistry which appears to be in a phase of rapid development.

This field of research is exacting in that the knowledge and techniques of so many branches of biology are involved, embryology, immunology, experimental surgery, protein biochemistry and serological biophysics. Team work is essential for progress and adequate supplies of experimental animals and considerable instrumentation are required, but, bordering as it does on so many of the active growing points of biological science, this work benefits from advances in each of these and in recent years progress has been correspondingly rapid.

- ¹ BRAMBELL, F. W. R., HEMMINGS, W. A. and HENDERSON, M. 1951. *Antibodies and Embryos*. London, Athlone Press.
- ² BRAMBELL, F. W. R. 1958. The passive immunity of the young mammal. *Biol. Rev.*, **33**, 488-531.
- ³ MASON, J. H., DALLING, T. and GORDON, W. S. 1930. Transmission of maternal immunity. *J. Path. Bact.*, **33**, 783-97.
- ⁴ CAROLI, J. and BESSIS, M. 1947. Recherche sur la cause d'ictère grave familial des muletons. *Rev. Hémat.*, **2**, 207-228.
- ⁵ DIMMOCK, W. W., EDWARDS, P. R. and BRUNER, D. W. 1947. Infections observed in equine foetuses and foals. *Cornell Vet.*, **37**, 89-99.
- ⁶ GOODWIN, R. F. W., SAISON, R. and COOMBS, R. R. A. 1955. The blood groups of the pig. II. Red cell iso-antibodies in the sera of pigs injected with crystal violet swine fever vaccine. *J. comp. Path.*, **65**, 79-92.
- ⁷ LEVINE, P. and STETSON, R. E. 1939. An unusual case of intra-group agglutination. *J. Amer. med. Ass.*, **113**, 126-7.
- ⁸ MORRIS, I. G. 1958. Experimentally induced haemolytic disease in young mice. *J. Path. Bact.*, **75**, 201-10.
- ⁹ BANGHAM, D. R., HOBBS, K. R. and TERRY, R. J. 1958. Selective placental transfer of serum-proteins in the rhesus. *Lancet*. 16 August 1958, 351-54.
- ¹⁰ CLARK, S. L. 1959. The ingestion of proteins and colloidal materials by columnar absorptive cells of the small intestine in suckling rats and mice. *J. biophys. biochem. Cytol.*, **5**, 41-50.
- ¹¹ HEMMINGS, W. A. 1957. Protein selection in the yolk-sac splanchnopleur of the rabbit: the total uptake estimated as loss from the uterus. *Proc. Roy. Soc., B.*, **148**, 76-83.
- ¹² HALLIDAY, R. and KEKWICK, R. A. 1960. The selection of antibodies by the gut of the young rat. *Proc. Roy. Soc., B.*, **153**, 279-86.
- ¹³ PORTER, R. R. 1959. The hydrolysis of rabbit γ -globulin and antibodies with crystalline papain. *Biochem. J.*, **73**, 119-27.
- ¹⁴ BRAMBELL, F. W. R., HEMMINGS, W. A., OAKLEY, C. L. and PORTER, R. R. 1960. The relative transmission of the fractions of papain hydrolyzed homologous γ -globulin from the uterine cavity to the foetal circulation in the rabbit. *Proc. Roy. Soc. B.*, **151**, 478-82.
- ¹⁵ BANGHAM, D. R., INGRAM, P. L., ROY, J. H. B., SHILLAM, K. W. G. and TERRY, R. J. 1958. The absorption of ^{131}I -labelled serum and colostral proteins from the gut of the young calf. *Proc. Roy. Soc., B.*, **148**, 184-91.

TASTE AND FLAVOUR

During the last ten years we in this country have experienced an abrupt transition from a state of bare sufficiency in food supplies to one of relative plenty. At the same time, but more gradually, a revolution has been taking place in marketing methods and in the preparation of foods in the kitchen. All, or almost all, kinds of fresh foods are in process of being pre-packaged and streamlined through a rapidly growing network of self-service stores and supermarkets. Food is becoming standardised and disciplined, and along with this evolution there is a growing awareness and complaint of lack of natural flavour. This has caught the agriculturalist and food scientist unprepared because it has never hitherto been thought worth while to spend much effort on the understanding of the nature of the tastes and flavours of our everyday foods, or on the methods of analysing and evaluating them. The remedy for lack of these qualities has always been available in the traditional "know-how" of the producer; but this "know-how" is on the way to being displaced by new production methods putting a premium on rapid yield and saving of labour.

There is, consequently, an urgent call for help in the evaluation or "measurement" of the quality of foods. There would seem to be two methods of setting out to provide this help: one is by putting subjective assessment of quality on a sound scientific basis; the other is by identifying the component elements of taste and flavour, working out precise analytical methods for their estimation, and making good deficiencies by appropriate supplementation.

It might seem at first sight that it would be a simple thing for the analytical chemist to measure many of the qualities contributing to taste and flavour. After all, sweetness is due to sugar and sourness to acid, and methods of estimating these constituents have been known for more than a century. But the difficulty is that analytical figures do not of themselves afford an index of these qualities. The sweetness of sugar solutions or the sourness of acids can so easily be affected by the presence of other constituents and by the circumstances in which they are offered to the palate. This is in fact easily appreciated by mixing sweet and sour things—the sweetness of the one, and the sourness of the other, are both diminished when they are mixed together—or by mixing in a tasteless thickener such as arrowroot. Another example is the saltiness of bacon: this can differ widely from one sample to another even though the chemist's analysis gives the same percentage of sodium chloride for the two samples. Nevertheless analytical figures do provide essential information, if only for the fact that they are incontrovertible when simple facts are in dispute. So it is necessary to consider what kinds of chemical knowledge can be usefully brought to bear on the subjective appreciation of taste and flavour.

THE CHEMISTRY OF TASTE

Taste is perceived by sensory receptors in the mouth, whereas flavour is perceived by the olfactory apparatus in the nose. The two kinds of sensation are in the ordinary way appreciated so simultaneously that a conscious effort is required to separate them. Pinching the nose when a highly flavoured food is being eaten helps to separate the one sensation from the other; the

flavour cannot then be detected, because the back-flow of air from the mouth to the olfactory apparatus is blocked, but the characteristic taste remains.

There are four main taste sensations: sour, salt, sweet and bitter. (Some writers regard the taste of meat as an additional primary taste sensation, but this is still open to argument.) Almost all the fundamental work on taste has been done with the idea that only the four primary tastes need to be reckoned with. There are specific receptors for each of these primary sensations, and their position can be plotted by applying minute amounts of appropriate substances to different areas of the tongue and buccal cavity. The receptors are situated in definite organs known as taste-buds, and it is interesting to note that after the age of 45 these begin to atrophy, so that sensitivity to taste slowly decreases with advancing age. It is likely that this is responsible for many complaints that foods "don't taste like they used to when I was a boy."

Besides these four taste sensations, there are many other kinds of sensation in the mouth that are commonly included in the vocabulary of taste. Sharp, pungent, burning and cold sensations involve the ordinary sensory nerve endings connected with the senses of touch and pain. Astringency, or puckering, is a most important component of flavour. This is often confused with bitterness, but is quite distinct, being due to the "tanning" of the saliva with metallic salt solutions such as alum or with vegetable tannins such as in tea and red wine. Roughness and smoothness and what is known as "body" are also important in taste. These properties, as well as toughness and tenderness, affect the length of time that the food is in contact with the gustatory surfaces. It is this factor which is responsible for the lack of exact correlation of the salt content of bacon and its saltiness as judged by the palate.

In the case of taste it is easy to account *qualitatively* for the sensations we experience in terms of the chemical constituents of the food, but these sensations may depart very considerably from a quantitative relationship with the analytical data. In the case of flavour, the situation is vastly more complicated because of the large number of different odours we can distinguish and identify, and the imperfect relationship between chemical structure and odour of different substances.

THE CHEMISTRY OF FLAVOUR

For substances to have a smell they must be in some degree volatile. Given this requirement, there are very few substances which do not have a more or less characteristic smell, but there are large differences between substances in the intensity of their odour. This means that constituents responsible for odour and flavour may be present in amounts too small to be analysed. It is known, for instance, that staleness in fish can be detected by the nose before the methylamines which are responsible for the staleness can be estimated chemically. Different classes of chemical compounds often have characteristic odours. It is therefore often possible to identify the classes of compounds responsible for natural flavours, and also those responsible for taints and off-flavours. With this information it is not too difficult a matter to devise analytical methods of estimating these constituents as a class, but it is seldom that this information can help to distinguish between good and inferior specimens of food. The criteria of goodness in flavour are as a rule too subtle for such relatively coarse analytical tools.

The difficulty is, of course, the multiplicity of organic substances of like chemical nature. There are potentially as many esters in a fruit, for instance, as there are combinations of naturally-occurring alcohols and naturally-occurring organic acids, and it is unlikely that it will be any one such combination which will be critically important in determining the desirable flavour of that fruit; although it may well be that the sum total of esters and their relative proportions may be the determining factor.

The case of esters in fruits is an example of the way flavours and odours are classified. These compounds are usually described as having a "fruity" odour. Other terms employed are spicy, flowery, resinous, burnt, and foul. Often particular elements or chemical groups are associated with the character of the odour. Thus the presence of sulphur is frequently associated with a foul odour, and that of nitrogen with a burnt odour. These two elements are particularly powerful in endowing the substances containing them with odour. It is for this reason that volatile compounds of sulphur and nitrogen, often in minute traces, are the cause of stale and putrid off-flavours in deteriorating foods. Also in minute traces, they are often responsible for the desirable flavours in exceptionally choice foods.

By way of illustration it will be useful to discuss what is known of the chemistry of some particular food flavours. Only a few foods have been the subject of extensive or intensive research from this point of view and so far the rewards have not been very great for the effort expended.

Coffee. It was confidently reported some years ago that the characteristic flavour of coffee is due to furfuryl mercaptan:—



Although, from what we have said above, this does not seem to be intrinsically unlikely, recent reports indicate a much more complex state of affairs. More than thirty odorous volatile components of roasted coffee have been identified; these include mercaptans, ketones, esters, aldehydes and heterocyclic compounds such as furfural. The question still remains open: why does coffee smell of *coffee*?

Pineapple. Here again it was reported some years ago that among the constituents of pineapple was a sulphur compound:—



that is, a methyl ester of an acid derived from the amino acid methionine by oxidative deamination. This, together with a mixture of methyl esters of low-molecular weight fatty acids, appears to be responsible for the characteristic flavour.

Cabbage. The characteristic odour of cabbage and other Cruciferae is associated with their specific constituents, the mustard oils. Among the volatile degradation products of these, butenyl isothiocyanate seems to be the one mainly responsible for the "cabbage" flavour:—



(The mustard oils themselves, which are responsible for the pungent character of the leaves and seeds, are more complex isothiocyanates.)

Cucumbers and other cucurbits. The fresh "green" flavour of cucumber is a specific variation on the theme of green leaf odour in general. This is due to six-carbon unsaturated compounds such as 2-hexenal:—



With increasing chain length the cucumber character begins to be evident, reaching a maximum with nonenal, the nine-carbon homologue. The bitter components of cucumber skin are sesquiterpenes. In some of the cucurbits these are exceedingly poisonous. The cultivated forms are ones in which the poisonous constituents have been bred out along with the disagreeable bitter character.

Meat. It is surprising how little is known about the nature of meat flavour. It has been claimed that one constituent of lean meat, glutamic acid $\text{HOOC} - \text{CH}_2 - \text{CH}_2 - \text{CH}(\text{NH}_2) - \text{COOH}$, is responsible for the characteristic sapid taste of meat, but it needs no more than a simple tasting test to throw doubt on the claim. Sodium glutamate in small amounts does, however, enhance the "meatiness" of soups and sauces.

Roast meat flavour, as distinct from that of raw meat, can be simulated by heating together certain amino acids and a reducing sugar such as glucose or fructose. This is important when we remember that meat is so much more often eaten in the cooked than in the raw state.

The specific flavours of the meat of different animals are for the most part associated with the fat. Flavours derived from the feed can also be detected in the fat, alfalfa flavour for instance in Argentinian and the aromatic veldt aroma in Rhodesian beef.

Butter. The characteristic flavour of butter is in large part due to diacetyl:—



This provides a good example of the way particular chemical groupings influence the odour of a substance. The saturated four-carbon chain containing two ketonic residues has an intensely strong pleasant sweetish odour. Acetylmethylcarbinol,



which is also present is less agreeable and much less strong by virtue of the substitution of a carbinol group for one of the ketonic residues.

These two substances are present in trace amount in many foodstuffs, especially those which have undergone fermentation, and contribute characteristically to their flavour.

Bread is one such foodstuff in which these substances are present. The odour of new bread is mainly due to furfural:—



which, as its name implies, is a product of the decomposition of bran, and is formed whenever carbohydrate-containing material (for instance coffee) is subjected to a roasting process.

ARTIFICIAL FOOD FLAVOURS

It is obvious that many of the substances mentioned above can be manufactured by the chemist and added to foods deficient in flavour or to

simulate other natural foods. In several instances the synthetic flavouring matter is truly indistinguishable from the natural one: such cases as vanillin and eugenol (the odorous constituent of clover) come to mind. Usually, however, the natural flavour is too complex for such perfect reproduction by artificial ingredients. It seems likely that there will be an increasing sophistication of foods along with the revolution in marketing to which attention was drawn in the opening paragraph. From the considerable extent to which this has already taken place it can be deduced that there will be two distinct trends: the introduction of entirely new and foreign attractive flavourings; and an ever closer approximation to natural flavour in the available artificial flavours.

Such sophistication of inferior foods is not, however, the first objective of the food scientist seeking to learn the composition of natural food flavours. Primarily it is to be in a position, by possessing such knowledge, to evaluate flavour by objective analytical methods in support of the subjective judgement of the professional taster; to preserve the fresh quality of natural produce during distribution and storage; and, quite legitimately, to make good the dissipation of flavour that always occurs through volatilisation or other causes in foods processed for long-term storage.

SUBJECTIVE ASSESSMENT OF TASTE AND FLAVOUR

We have mentioned in the last paragraph the "subjective judgement of the professional taster." In addition to the well-established practice of such experts in tasting such commodities as tea, wine and cheese, there is growing up a technique of tasting by laboratory panels trained for the purpose of the immediate test or experiment. A great deal is being written in the technical journals about the ways in which the accuracy and reliability of the judgements pronounced by such panels can be improved. Their great disadvantage is that so much time and labour has to be expended on them. It is, nevertheless, abundantly clear that it is only by such panel judgements that answers to questions involving taste and flavour can be obtained. As we have seen, analytical data are no more than analytical data: it is the actual experience of the consumer that is the only true and final criterion of the character and intensity of a taste or flavour sensation.

The most determined attempt to set up a discipline of flavour assessment is the one known as the "flavour profile method" introduced by Cairncross and Sjöström ten years ago. Its terminology is derived from that of perfumery and other arts in its use of such terms as "notes" and "amplitude." The authors summarise their method in the following words: "The Flavour Profile presents a descriptive analysis of flavour expressing in common language terms the characteristic notes of both aroma and flavour, their order of appearance and intensities, and the amplitudes of total aroma and flavour." As an example, the component sensations relevant to the flavour of beer are listed as salt, sweet, sour, fruity, bitter, yeast, malt, phenylacetic acid, skunk, metallic, astringent, and others (as may be detected). (As in the case of phenylacetic acid direct association with a definite chemical is attempted whenever possible.) These "notes" are listed on a score-sheet, with columns provided for scoring intensity and amplitude of each "note."

This is not very different from the conventional approach to subjective assessment, but it stands out by virtue of the uncompromising way in which it

matches language to experience rather than forcing experience to conform to language. This does in fact seem to be an important feature, because the whole difficulty in this field lies in the accurate communication of experience.

By such means as these, and with a degree of success varying widely from one commodity to another, food scientists are beginning to pin-point the respects in which samples differ from one another. This then enables the biochemist to follow on with his chemical and physiological studies. Even though these were to reach the ultimate finality of chemical analysis, the gap would have still to be bridged between the assessment of particular characteristics and their significance in relation to the consumer's likes and dislikes and the value of the commodity on the market. This is an integration which the expert taster achieves in putting a price on the samples presented to him for his opinion. While the scientist can provide information on which a decision can be based, whether that information is obtained by objective or subjective procedures, the reaching of a decision is not strictly his concern; though there is no reason why he should not make it his concern, but in a rather different capacity.

TASTE, FLAVOUR AND THE CONSUMER

At intervals throughout this article the consumer has come up for mention. In the opening paragraph he was mentioned as beginning to complain about the general lack of flavour in present-day food, and a little later it was pointed out that this might be attributable, at least in part, to the degeneration of his taste-buds with advancing age. It would almost seem that there is a feeling abroad that to be really wholesome foods should be as nearly colourless, odourless and tasteless as their particular nature permits. The producer produces what the consumer wants, as demonstrated by what he actually purchases. It is for the consumer to demonstrate his needs in such unmistakable terms that the producer can set out to satisfy them.

Increased knowledge of the nature of the constituents of foods responsible for taste and flavour and methods of estimating them and above all reliable methods of evaluating the desirable qualities of foods by subjective methods, can be of the greatest possible service to both consumer and producer, especially at this time of rapid transition in methods of producing and marketing agricultural produce of all kinds.

THE IRRIGATION OF VEGETABLES IN THE UNITED KINGDOM

During the past decade there has been increasing use of irrigation for a wide range of crops from grass to high-value horticultural crops. The summer drought of 1959 and the shortage of rain in the first half of 1960 intensified interest in irrigation. In time of drought, domestic users and industry have prior claim on supplies, while growers and farmers must make the best use of what is admittedly insufficient water to meet all their needs.

Even in a summer of average rainfall this country's water supplies are barely sufficient to meet existing demands, and results of a recent survey of one river basin¹ have suggested that, if the present annual rate of increase in demand for irrigation is maintained, supplies in that locality will fall short of requirements within the next ten years.

The advisability of installing irrigation equipment on particular land depends upon the locality, upon the crops grown, and upon the adequacy of water supplies in time of drought.

For horticultural crops, irrigation has already come to be regarded as a necessity rather than a luxury. In comparison with farm crops, however, the area of land devoted to market gardening is small; therefore the overall proportion of the national water resources required for irrigating horticultural crops might appear to be relatively small. Nevertheless, in dry weather, the demand on *local* resources in market gardening areas is often embarrassingly high. It is important, therefore, that all water for irrigation, whether on farm or market garden, be used with the maximum efficiency and that haphazard irrigation be discouraged. Irrigation should be carried out only with a particular object in view, such as a planned increase in yield or quality of the produce, or the facilitation of cultural operations.

The present article reviews the state of our knowledge of the irrigation of vegetables, especially from the point of view of economy in water and the efficiency of its utilisation.

THE DETERMINATION OF IRRIGATION NEED FOR VEGETABLE CROPS

Penman and his colleagues² have prepared maps which show that the frequency of irrigation need is greatest in the south-east (in Kent irrigation is required in nine years out of ten), and least north-west of a line from Cornwall to the East Riding of Yorkshire, being almost nil in North Wales and Cumberland.

In this work they have assumed that, provided soil moisture is not limiting, the potential rate of transpiration from a green crop fully covering the soil is controlled entirely by current weather and that growth will be adversely affected if the soil moisture content falls to such an extent that the actual transpiration rate becomes less than the potential rate. However, at conventional spacings, most vegetable crops fully cover the soil for only a comparatively small part of their life; furthermore, especially in the early stages of growth, the moisture content of the upper layer of soil in which most of the plant roots occur can frequently fall below the level at which the transpiration rate might be expected to be reduced.

Minor modifications to Penman's original method of estimation have therefore been developed to take into account the percentage of the soil surface covered by foliage, the interval of time since the soil surface was last wetted, and the season of the year. These modifications have been used successfully in experiments on the irrigation of vegetables at the National Vegetable Research Station, and at the Experimental Horticulture Stations of the N.A.A.S.³

The meteorological approach to water use by plants is based on the assumption that transpiration is a passive process related solely to weather conditions and not to the type of plant. Thus it has been assumed that under given conditions all plants transpire the same quantity of water per unit area of foliage-covered soil. There is experimental evidence, however, that carrots and grass, for example, may transpire different amounts while growing under the same environmental conditions.⁴ Furthermore, under certain circumstances the actual

transpiration from experimental plants has apparently exceeded the maximum potential transpiration according to meteorological considerations; more research is needed to elucidate these anomalies. The resulting errors in estimating irrigation need, however, are apparently not large enough to invalidate the use of the meteorological concept for practical purposes.

A more serious difficulty in the use of weather data for estimating the irrigation need of comparatively shallow-rooted vegetables arises from the fact that the water-holding capacity of a heavy soil is greater than that of a light soil. Thus, an inch of water lost from the top foot of a soil might represent half the amount of available water in a clay soil, but the whole of the available water in a sandy soil; the loss of the same estimated quantity of water, i.e. an inch, from the two soils would impose very different moisture stresses on vegetables growing in them.

As moisture is removed from the soil by evaporation and by root action, the remaining water is held with increasing tension. The relationship between soil moisture tension and soil moisture percentage varies for different soils and is expressed as the "soil moisture release curve." The tension with which a soil holds its moisture affects the availability of water to plants and consequently alters the responses of crops to irrigation treatments. Moisture release curves enable the results of irrigation experiments conducted on one soil type to be interpreted in terms of another.

Numerous attempts have been made to simplify the meteorological method for determining irrigation need. For the determination of the amounts of water to be applied in commercial irrigation it has been found satisfactory to replace actual measurements of meteorological factors by long-term average figures which have been computed for most of the important agricultural districts. Subtracting measured rainfall from the current local average gives an estimate usually within half an inch of the true soil moisture deficit.

As an alternative to an estimate based on weather data, it is possible, of course, to assess the soil moisture status by direct measurements either on samples abstracted from the soil or at a number of points *in situ*. The measurements may be of percentage water content of the soil, or of different properties associated with this such as electrical resistance or capacitance of probes, heat conductivity or soil moisture tension.⁵ Of these, only the last has been used to any considerable extent in this country.^{6, 7, 8} At present it seems unlikely that any of these methods will prove suitable for commercial use because of the expense and delicacy of the apparatus involved, and of the difficulty in obtaining readings from sufficient samples to give an adequate picture of the soil moisture status over the whole rooting depth of the plants. On the other hand, a simple instrument has been devised which automatically integrates the water loss from a special surface and the water gain from rainfall, thus giving a direct indication of the probable current soil moisture deficit.⁹

SOME EFFECTS OF SUPPLEMENTARY WATERING ON THE GROWTH AND YIELD OF VEGETABLES

There is a limit to the amount of water which a particular soil can hold (field capacity); water added after this condition has been reached is wasted because an equal volume drains away. Thus, in contrast to the result to be expected from increased fertiliser application, which usually follows a law of

diminishing returns, there is a sharp limit beyond which further application of water has no beneficial effect.

With most plants, copious watering has been found to encourage the production of foliage but in vegetables this is not always accompanied by proportionate increase in yield of non-foliar marketable material. Thus, although pea plants irrigated before they had flowered produced more foliage than those which received only rainfall, there was no difference in the eventual yield of shelled peas. Increased yield of peas was obtained, however, by watering *after* flowering, when the pods had set. A further yield increase was obtained by a light watering (about $\frac{1}{2}$ inch) a few days before harvest.¹⁰ Incidentally these late post-flowering waterings had the additional important effect of delaying the rise in tenderometer reading (equivalent to the increase in content of alcohol-insoluble solids) and thus extending the period during which the produce was suitable for deep-freezing or canning. In contrast, cauliflowers grown throughout their lives under comparatively wet conditions not only produced more foliage than when grown under drier conditions, but also produced larger, heavier curds.¹¹

The best watering treatment for some crops depends upon the purpose for which they are being grown. For example, results of experiments suggest that early potatoes should be well supplied with water from the time the young shoots emerge from the ground in the spring. This has been found to encourage general growth so that the young tubers reach marketable size earlier than those which have suffered a check from water shortage. The higher price fetched by early potatoes marketed only a few days ahead of the average makes irrigation of this crop worthwhile.

With maincrop potatoes, on the other hand, the date of maturity is comparatively unimportant; the cash return depends mainly upon the weight and quality of the crop. Prevention of water-stress after the formation of young tubers has resulted in increased yield at maturity. Watering before the young tubers had formed, however, merely increased the amount of foliage produced, and the yield of potatoes was unaffected; this was, therefore, a waste of effort and of water.¹²

The increase in yield per inch of water applied may vary; thus, in an experiment with early summer cauliflower,¹³ six irrigations (totalling 3 inches of water), spaced over the whole field life of the crop, increased the average curd diameter by 0.8 inch, i.e. an increase of 0.27 inch per inch of water applied, whereas a single irrigation of 1 inch near to harvest time increased the curd diameter by 0.6 inch.

EFFECTS OF VARYING THE QUANTITY AND FREQUENCY OF IRRIGATION

It is not possible by ordinary means to maintain a constant moisture content in a soil in which plants are growing, nor is it possible to raise the moisture content of a soil to any level other than field capacity—the state in which a freely-drained soil is holding its maximum possible quantity of water against the pull of gravity. Varying the quantity of water applied to the soil surface merely varies the depth to which the soil is brought to field capacity. (The transient state of “saturation” is here ignored.)

Plants in the field thus experience periods of slowly falling soil moisture content, alternating with periods of rapid recovery to field capacity, to soil depths varying according to the quantity of water which has fallen on the surface. A plant growing in the open in a wet summer is subject to frequent comparatively small natural applications of water, and these have the effect of keeping the moisture content of the whole of the soil pervaded by its roots fluctuating between field capacity and only slightly below that state. This wet environment (which might be expected to be optimal for plant growth) can be imitated in practice by frequent small irrigations, but this is expensive in labour, and moreover is wasteful of water. After each watering, evaporation takes place from the foliage and from the soil until the surface of both is dry; the waste of water from wet exposed soil by this cause can be up to half an inch per irrigation and it is important to note that the amount of waste will be about the same irrespective of the total quantity of irrigation applied.

Economy in both labour and water would be effected by irrigating at long intervals and with comparatively large applications, but this would subject the plants to long periods during which the soil moisture content would be falling to a comparatively low level, alternating with rapid recovery to field capacity. The effect on different plants of this wide fluctuation in soil moisture environment have not been fully investigated.

Water economy, effected by reducing the amount of irrigation below that needed to restore to field capacity the full depth of soil penetrated by the roots, subjects the root system to differing moisture stresses at different levels. Results of recent work indicate that the whole of the water requirement of the lettuce plant may be satisfied by absorption through only a portion of its root system; the nutrient requirements also may be fully supplied by only part of the root system and not necessarily that part which is absorbing most water. No adaptation of lettuce roots to absorption of nutrients or water was observed.¹⁴ Thus there would appear to be no reason why the full water requirement of a crop might not be met by irrigating with sufficient water to restore only part of the root zone to field capacity.

The proportion of the root system of each crop which should be fully supplied with water at each irrigation will probably differ for different crops and at different stages of growth, and should be the subject of further research.

OTHER CONSIDERATIONS

Disease. It has been suggested that irrigation may affect the spread of disease but little direct evidence is available on this point; it is obviously unwise to sprinkle-irrigate crops of potatoes in which blight is already rampant. As regards storage, there is no experimental evidence that produce from irrigated plants keeps any less satisfactorily than non-irrigated produce.

Crop quality. The effects of irrigation on flavour are sometimes beneficial and sometimes detrimental.¹⁵ Whereas carrots grown with an ample water supply looked plump and well coloured when raw, after cooking they lacked flavour and sweetness as compared with carrots grown under dry conditions; the latter, however, would have been unsaleable on account of their emaciated appearance. When irrigated turnips were cooked they had a milder flavour and a less fibrous texture than non-irrigated turnips. Lettuce grown under a wet regime were crisp and mild-flavoured compared with those grown under a

dry regime, which were "hot" and tough. Tomatoes grown under wet conditions were attractive in appearance, but had poorer flavour than those grown under drier conditions.

Crop earliness. Increasing the soil moisture supply has been found to cause many plants to increase in size. This can have the beneficial effect of causing organs already formed to reach marketable size sooner, as with early potatoes or cabbage, but often it can cause the general rate of development of the plant (as opposed to mere growth in size) to be slowed down. Thus, irrigated cauliflowers matured a few days later than non-irrigated ones¹⁶ and irrigated peas ripened later than peas grown under drier conditions.

Fertiliser application. It is a common glasshouse practice to supply nutrients dissolved in the irrigation water—for example, to the tomato crop. Application of fertilisers in field irrigation water is less common but some highly successful growers use this as their normal method of applying artificials. Little critical work as been done to assess the relative merits of applying fertiliser in solution and of applying it dry in the usual way.

Water temperature. In view of the sensitivity of plants to changes in environmental temperature, some growers are reluctant to irrigate with water colder than the air, such as may be obtained directly from certain boreholes. Experiments have shown that, although reducing the temperature of the roots by saturating the soil with cold water can reduce growth and eventual yield, this is unlikely to occur in practice because, irrespective of the supply temperature, water sprayed through the air with commercial irrigation equipment is virtually at air temperature when it reaches the soil.

Water purity. Water for ordinary irrigation need not be as pure as water for domestic and many industrial uses; therefore, in view of the national shortage of water, it would seem reasonable to irrigate as far as possible with water abstracted from rivers and streams or stored locally by impounding flood-water and winter land-runoff.

The main contaminants in river water are sewage effluents—treated and untreated—factory discharges (some of which contain phytotoxic metals), and detergents. The highest irrigation demand is likely to correspond with the lowest river-flow but the volume of sewage effluent, laundry and factory discharge into rivers is not directly related to the weather. Thus the concentration of contaminants in river water will probably be highest at the time of maximum irrigation need. In addition to a direct toxic effect on plants of certain contaminants, repeated irrigation with water containing detergents could affect the water-holding capacity of the soil, and this effect would be more serious on sandy soils than on heavier soils. With certain well-known exceptions, the detergent concentration in most rivers flowing through agricultural areas is not yet high enough to affect crop growth.

A more immediate danger lies in the use of brackish water for irrigation, such as may be found in drainage channels near the East Coast and in a few inland sources. There is little experimental evidence on the degree of tolerance to sodium chloride shown by crops in the field. Apparently certain crops, such as beet, can tolerate a higher concentration than others, and a form of adaptation to increasing doses of salt has been postulated but more research is needed into this whole problem.

FUTURE RESEARCH AND ECONOMY IN THE USE OF WATER

Economy in the use of water implies using whatever volume of water is available in the way which gives the largest increase in net output of produce.

On most market gardens a variety of crops is grown, most of which, as has been pointed out, are likely to respond to watering during dry weather by increasing growth but not necessarily always by increasing marketable yield. Except for the increased quantity of foliage which results from irrigating most plants, there is apparently no simple pattern of response to supplementary watering which is common to all vegetables. Thus it is necessary to determine for each kind of crop the best watering treatment throughout its life, the stage of growth at which watering results in the largest marketable yield increase and the effects of restoring to field capacity only a part of the soil occupied by its root system.

Irrigation in apparently suitable amounts has sometimes been found to depress the yield of certain crops; this has been attributed to damage to soil tilth or possibly to foliage, caused by the impact of water drops whose average size was probably larger than that of ordinary rainfall.¹⁷ There are practical difficulties, however, in applying irrigation water using a reduced water-drop size. Existing equipment will not throw small drops as far as large drops, and wind interferes with the distribution of small drops. Research is needed, therefore, into these engineering aspects as well as into the biological effects of varying the drop size of irrigation water. It has been suggested that damage to the soil tilth might be avoided by mulching with, for example, plastic sheeting, or with granular or fibrous materials such as sand or peat. Mulching with an impervious material could have the additional advantage of reducing the loss of water by evaporation from the bare soil surface but it might be necessary to take precautions to ensure adequate aeration of the soil beneath such a mulch.

In certain circumstances irrigation only at discrete points on the soil surface as with the various glasshouse "trickle" systems, might prove advantageous in eliminating tilth damage caused by drop impact while at the same time leaving most of the soil surface dry, and not liable to lose water by evaporation. Water lost by evaporation from the soil surface, with a vegetable rotation under average conditions, has been estimated at nearly one-third of the total annual rainfall. Material reduction in loss by evaporation, therefore, could substantially reduce the need for irrigation.

CONCLUSIONS

In most seasons it is unlikely that many growers will be in a position to supply all their vegetable crops with sufficient supplementary water to obtain the maximum marketable yield, partly because of national difficulties in meeting the growing demand for water for domestic and industrial purposes, and partly because the need to keep rivers flowing limits the amount of local abstraction permissible during dry weather. Furthermore, the cost of irrigation equipment and labour is likely to be a limiting factor in the total amount of irrigation water applied.

Therefore, one of the primary objects of research must be to determine how to use limited irrigation to the best advantage. This entails specifying the stages of growth at which different vegetables give the largest yield response to irrigation. Coupled with this must be research into different aspects of the

problem of irrigating in the manner which causes least damage to the soil, and in methods of reducing losses by evaporation. The most efficient irrigator is he who uses the least amount of water to the best advantage in terms of increased yield of high quality crops.

- ¹ *Hydrological Survey of Great River Ouse Basin.* H.M.S.O. 1960.
- ² PEARL, R., PENMAN, H., *et al.* The calculation of irrigation need. *Min. Ag. and Fish. Tech. Bull. No. 4.*
- ³ STANHILL, G. 1958. The estimation of evapo-transpiration from meteorological data. (Unpublished pamphlet for internal use at N.V.R.S., Wellesbourne).
- ⁴ STANHILL, G. 1958. Further studies on the loss of water from plant/soil systems. *Rep. Nat. Veg. Res. Sta. Wellesbourne for 1957*, 40-41.
- ⁵ EASTWELL, B. 1953. *In situ* methods of measuring soil moisture content—a critical résumé. *Elec. Res. Assoc. Tech. rept. W/T27.*
- ⁶ GOODE, J. 1956. Soil moisture relationships in fruit plantations. *Ann. appl. Biol.*, **44**, 525-530.
- ⁷ SALTER, P. 1954. The effects of different water-regimes on the growth of plants under glass I. *J. hort. Sci.*, **29**, 258-268.
- ⁸ HACK, H. 1957. An automatic null method recording manometer. *J. Sci. Inst.*, **34**, 280-282.
- ⁹ STANHILL, G. 1958. An irrigation gauge for commercial use in field and glasshouse practice. *J. agric. Eng. Res.*, **3**, 292-298.
- ¹⁰ SALTER, P. 1960. Irrigation of peas. *Rep. Nat. Veg. Res. Sta. Wellesbourne for 1959*, 31.
- ¹¹ SALTER, P. 1959. The effect of different irrigation treatments on the growth and yield of early summer cauliflowers. *J. hort. Sci.*, **34**, 23-31.
- ¹² NORTH, J. 1959. N.A.A.S. West Midland Region "Experiments" for 1958 and 1959.
- ¹³ SALTER, P. 1960. Irrigation of Cauliflowers. *Rep. Nat. Veg. Res. Sta. Wellesbourne for 1959*, 30-31.
- ¹⁴ DREW, D. 1960. Studies on Root Systems. *Rep. Nat. Veg. Res. Sta. Wellesbourne for 1959*, 31-32.
- ¹⁵ STANHILL, G. 1957. Irrigation of Carrots. *Rep. Nat. Veg. Res. Sta. Wellesbourne for 1956*, 47.
- ¹⁶ SALTER, P. Effects of different soil moisture conditions during the seedling stage on the growth and yield of early summer cauliflowers. *J. hort. Sci.*, **35**, (in the press).
- ¹⁷ BLACKWALL, F., LUCY, C. and WINTER, E. 1960. Irrigation of a rotation of vegetable crops. *Rep. Nat. Veg. Res. Sta. Wellesbourne for 1959*, 32-33.

THE AIRTIGHT STORAGE OF GRAIN

Since the war, the increasing use of combine harvesters in this country has thrown emphasis on the problem of safe storage of the harvested grain. Whereas formerly stooking and rick-stacking of the unthreshed crop allowed the grain to dry out gradually before threshing, today large quantities of threshed grain are produced in the relatively short period of harvest. Much of this grain is of fairly high moisture content and has to be dried artificially before it can be stored. In bad seasons this is expensive and imposes a great strain on drying facilities. Various methods have been sought which might help overcome the problem of storing damp grain. One of these is airtight storage, which has been known for centuries as a successful means of preserving dry grain.

In recent years airtight or hermetic storage of relatively damp grain has been developed commercially in France. There has also been a revival of interest in

it as a means of controlling insect infestations, particularly in tropical countries. Both these developments are of possible interest under British conditions and are therefore discussed in the present article.

Both depend on the same principle for their success—the exclusion of oxygen from the stored grain. The rate of respiration, and hence of heat production, of dry, uninfested grain is low. If grain is damp or heavily infested by insects, however, it can, under conditions of normal air supply, become heated. This is due to the respiration of the moulds that develop because of the dampness, or to the respiration of the insects infesting it. When such grain is kept under airtight conditions, the oxygen in the intergranular air is soon used up by the aerobic moulds or the insects present, and is replaced by carbon dioxide. If no more air can enter, the oxygen will fall to a low level and the harmful organisms, moulds or insects, will die, as a result of their own activity, before they have become numerous enough to cause serious damage. It was at first thought that the accumulation of carbon dioxide causes death, but it has now been confirmed² that for insects, it is the depletion of oxygen that is the lethal factor. It has also been shown⁸ that moulds can grow in a high concentration of carbon dioxide if the oxygen supply is not limiting, but that they will die if the oxygen is reduced to a low level.

Even at very high moisture contents (up to 30 per cent) mould growth is prevented by airtight storage. In such conditions, however, the grain often undergoes certain changes, which may make it unsuitable for human food though still suitable for animal feed.

DAMP GRAIN

Just over one hundred years ago there was a revival of interest in France in airtight storage of grain. Doyere, in 1853, carried out tests in underground silos at a number of garrisons and prisons. Muntz later experimented with semi-underground concrete bins lined with metal plates, in which storage was generally successful unless there was leakage at the bolted seams. More recently, Blanc showed that it was not necessary for the silos to be underground and that when complete airtightness could be obtained, by the use of a welded construction, wheat of 16 per cent moisture content (the highest he could obtain) could be stored successfully for eighteen months in an above-ground metal bin.

In recent years welded metal bins of cylindrical or hexagonal construction have been built in a number of places in France⁵ to store grain, usually at not more than 17 per cent moisture content, but sometimes at 18–19 per cent and occasionally at 21 per cent. The bins used, of 100–190 tons capacity, are usually arranged in groups of 4 to 28, and many are owned or managed by agricultural co-operatives.

Because of the advantages to British agriculture if airtight storage could be used successfully here, tests were begun in 1952 at the Pest Infestation Laboratory, and have recently been concluded. Only some of the results have yet been published^{6, 7} although interim reports have appeared in *Pest Infestation Research* from 1953 to 1957.

The tests were carried out both on a laboratory scale and in 10-ton welded steel bins, with wheat or barley of from 17–24 per cent moisture content, with controls at 12–14 per cent.

The experiment showed that the hermetically-stored grain remained bright and free-flowing, even at the highest moisture contents and for the longest periods studied—18 months at 24 per cent moisture content and 5 years at 17 and 19 per cent. It was not visibly mouldy and showed no signs of heating. At moisture contents of 17 per cent and above, the grain developed a sour-sweet smell and taste which, at the highest moisture levels or with prolonged storage, could not be removed by subsequent airing or drying.

Except in the control containers with dry grain, where the amount of carbon dioxide in the intergranular air did not rise above 2 per cent in 18 months, anaerobic activity caused an appreciable increase in the amount of carbon dioxide. In the dampest grain (24 per cent moisture content) the concentration rose to 95 per cent and there was an increase in pressure inside the container which under commercial conditions would have had to be released. The oxygen concentration was reduced to a very low level (0.1 to 0.2 per cent) in all containers except those containing dry grain, where it remained high.

The viability of the grain was reduced at high moisture levels, the rate and amount of reduction in germination varying with temperature and moisture content. At low moisture levels (below 14 per cent), the germination remained high for several years.

Milling and baking tests on the grain carried out by the Cereals Research Station at St. Albans showed that at high moisture contents there was a slight effect on the milling properties and an appreciable effect on the baking quality. Chemical changes involving the gluten and changes in the amount of reducing and non-reducing sugars were sufficient to affect the properties of the dough and the volume, crumb structure and colour of the resultant loaves. The taint noticed in the grain was carried over to the flour and at very high moisture levels was detectable in the bread produced from it. The effect of most of these changes was lost when the grain was mixed with a high proportion of normally-stored grain; this is the custom in France, where some adverse changes due to this form of storage are apparently accepted by the millers.

Feeding tests carried out on poultry with the co-operation of a number of individuals and organisations (see *Pest Infestation Research*, 1955, p. 22) indicated that the nutritive value of the grain was not impaired, nor did the tainted grain have any detectable effect on the birds, or on egg production.

Results similar to those obtained in England have been reported from the U.S.A. in tests on high moisture maize³, where hermetically-stored grain of up to 27 per cent moisture content has been fed successfully to pigs. Tests on rice of up to 32 per cent moisture content have shown that it can be kept mould-free under completely airtight conditions.

Recently, Russian workers¹⁰ have reported laboratory tests which confirm the results of the English experiments, particularly the changes in the intergranular atmosphere, chemical changes in the grain and loss of viability at high moisture content.

The adoption of hermetic storage for damp grain thus seems to be limited by certain adverse effects which appear at high moisture content. The method would obviously not be a suitable one for the storage of seed grain; nor would it be suitable for grain for human food, unless the grain were subsequently diluted with normal grain. However, there may be circumstances in which

airtight storage of damp grain might be valuable—for example, if the grain is to be used for animal feed.

It should be noted that the usual type of storage bin would not be adequately gas-tight. Any bins used for the hermetic storage of damp grain should be of welded metal construction.

DRY GRAIN

Dry grain stored under airtight conditions undergoes none of the harmful changes that develop in damp grain. Moreover, the degree of airtightness is not so critical; dry grain can be successfully stored even when there is a slight leak of air, provided this is very small. It is therefore easier to construct suitable containers.

Airtight storage of dry grain for the control of insect pests has been and still is used in many parts of the world, particularly in warmer countries where infestation problems are acute. It could be used even more extensively if its advantages were more widely known. Many of the storage structures used in the countries of the Middle East and India are airtight or nearly so. They often consist of chambers or pits in the ground, constructed either singly, often under houses, or arranged in groups as are the fossae in Malta and the pits in Egypt and Cyprus, which have small domed openings projecting at the soil surface. When hollowed out of the solid rock they need virtually no additional strengthening, although measures have to be taken to absorb soil moisture. When the pits are dug in ordinary soil, however, as in the recent re-development of underground storage in Argentina and elsewhere, the walls and base have to be made of reinforced concrete and treated with an impermeable substance such as bitumen to make them water- and gas-tight⁴.

The extension of underground storage in Argentina and other South American countries, where several million tons are now stored annually, dates from the war-time years when the surplus grain could not be shipped overseas. The pits, constructed to the design of C. O. Lopez¹, were, after filling with grain, at first covered with layers of bitumenised felt, with or without earth on top. Later, permanent domed covers with sealable hatches were developed. Underground structures are made airtight more easily than those above ground, and have the further advantage that the supporting soil allows the concrete walls to be thinner, as well as providing a certain amount of thermal insulation for the grain. Care in choosing the site, which must be in firm soil with the water-table well below the bottom of the pit, and in the construction of the pit itself, is essential¹¹.

A further development of airtight storage has been the recent (1955) erection in Cyprus of eight 1,000-ton bins*, with a conical below-ground portion and an above ground ctesiphon dome⁹. These, as are most kinds of large underground stores, are intended primarily for long-term storage, and grain has been kept successfully in the bins in Cyprus for four years. Bins of this type can obviously be used for season-to-season storage. They can be constructed in such a way as to enable the grain to be handled largely by mechanical means, if the necessary machinery is available. Smaller versions could be filled by manual labour.

The degree of air-tightness required for the control of insects is less severe than that required for moulds, and the bitumen-treated concrete mentioned

* of registered design.

is generally sufficient if the construction is sound and all openings adequately sealed. Provided the oxygen concentration becomes sufficiently reduced and remains low for long enough to kill the insects, subsequent slow re-entry of air is not important.

The possibility of using airtight bins for storing dry grain in this country is certainly worth considering, for it makes the grain completely safe from insect attack. Tests are being carried out at the Pest Infestation Laboratory on the use of different constructional materials, including bitumenised concrete and various synthetic materials and plastics. Some of the preliminary results are encouraging. It is hoped that storage trials may later be extended to the farm.

One cannot end this account of airtight storage without a word of warning. Many of the modern "plastic" materials are truly airtight, others are not, and allow oxygen to pass through, albeit slowly. Unfortunately some of the latter, such as polyethylene, are very impermeable to water vapour, and if used to enclose stacks of bagged grain, any moisture present is prevented from escaping. This of course applies to any airtight structure, but is more dangerous in these water-proof films that admit air. Their use to cover stacks of newly harvested or newly dried grain, which may be relatively warm, could easily lead to trouble. As the grain cools down in autumn, temperature gradients developing between the centre of the mass and the outer layers may cause migration of moisture with condensation in the cooler parts, often under the plastic sheet. This could result in sprouting of the grains and serious development of moulds. Successful storage in plastic containers may be possible, but more experimental work is needed before the proper conditions for it are known.

- ¹ ARGENTINE MINISTRY OF NATIONAL ECONOMY. 1951. Storage in underground silos. *Proc. U.N. Sci. Conf. Conserv. and Utilisation of Resources, Lake Success 1949*, 1951, 6, 356-358.
- ² BAILEY, S. W. 1955-57. Air-tight storage of grain; its effect on insect pests. *Aust. J. agric. Res.*, 6, 33-51; 7, 7-19; 8, 595-603.
- ³ FOSTER, G. H., KALER, H. A. and WHISTLER, R. L. 1955. Effects on corn of storage in airtight bins. *J. agric. Fd. Chem.*, 3, 682-686.
- ⁴ HALL, D. W., HASWELL, G. A. and OXLEY, T. A. 1956. Underground storage of grain. *Colonial Research Studies* No. 21. H.M.S.O.
- ⁵ HYDE, M. B. 1953. Air-tight storage of grain. *Field*, 202, 1050-1051.
- ⁶ HYDE, M. B. and OXLEY, T. A. Experiments on the airtight storage of damp grain. I. Introduction, effect on the grain and the inter-granular atmosphere. (In the press.)
- ⁷ OXLEY, T. A. and HYDE, M. B. 1957. The air-tight storage of damp grain. *Fm. Mechaniz.*, 9, 473-474.
- ⁸ PETERSON, A. *et al.* 1956. Grain storage studies XXII. Influence of oxygen and carbon dioxide concentrations on mould growth and grain deterioration. *Cereal Chem.*, 33, 53-66.
- ⁹ RANSOM, W. H. 1960. Buildings for the storage of crops in warm climates. *Tropical Building Studies* No. 2. H.M.S.O.
- ¹⁰ SHVETSOVA, V. A. and SOSEDOV, N. I. 1958. (Biochemical changes during prolonged hermetic storage of wheat) (in Russian). *Biokhim. Zerna*, 4, 229-240.
- ¹¹ SWAINE, G. 1954. Underground storage of maize in Tanganyika. *East Afr. agric. J.*, 20, 122-128.

MUTATION BREEDING

Mutation breeding is a term which has been widely used during the last ten years in both popular and scientific writings. It embraces the techniques of treating whole plants or parts of plants with mutagenic agents and attempting to utilise the mutations thus produced in the improvement of crop or ornamental plants. Like other new techniques it needs to be examined carefully so that its true value can be determined and extravagant claims exposed. There is a tendency for new methods in many branches of science to be given undue prominence until they eventually find their true level; for example the production of polyploids by using colchicine has not proved universally valuable as a means of improving crop plants but it is, nevertheless, useful in some lines of research. Enough work on the induction of mutation has now been done to make a provisional estimate of its value in plant breeding but it is important to remember that while mutagenic agents and new ways of applying them are still being explored no final assessment can be made.

With each crop the study of mutation breeding has passed through a preliminary stage during which the aim was frequently no higher than to see what treatments were effective and what sorts of changes could be produced. The dose necessary to affect a plant was found to vary greatly from species to species and the range of mutant types was also variable since it depended on the morphological and other characters of the plant which were readily observable. From this approach to the subject there emerged two main claims for the application of mutation breeding to crop plants. One claim is that some objectives can be achieved more easily, that is with less work or in a shorter time, by the induction of mutations than by hybridisation; secondly it has been claimed that the mutation method can produce results not obtainable by other means. In judging these claims it must be remembered that all research, whether applied or not, makes demands on finances which are necessarily limited and that it is the duty of the research worker to make the best uses of the resources available to him. It is important therefore to consider not just what has been achieved by mutation breeding but how this achievement compares with the likely results of applying the same effort to more conventional methods. If mutation breeding can achieve results not otherwise obtainable then clearly they must be judged by their economic or academic value in relation only to the cost of producing them.

A modern crop variety needs to be extremely well adapted to its environment and must consequently have a very precisely adjusted genetical constitution or genotype as it is called. It is not surprising, therefore, that it is easy to disturb this genotype adversely and difficult to improve it by the chance alterations known as mutations, the vast preponderance of which are deleterious when measured in terms of crop production. For many crops the days of trying mutation breeding "to see what happens" are past and the breeder should have a clear idea of what he is proposing to do and what are the objectives of the programme. When he has defined his objectives and decided that the induction of mutations is a sensible procedure he must consider how he will recognise the mutants he seeks amongst large numbers of unaltered plants. The numbers need to be large because mutations of a particular kind are usually very rare events and populations of only a few thousand plants are not very likely to contain what is wanted. On the other hand, the larger the population

the greater is the difficulty in finding the desired type and some compromise must be reached in practice. Some mutants can be isolated fairly readily when they occur at frequencies of 1 in 10,000 or even 1 in 100,000 plants, because there are efficient tests for their identification. A good example of these is the production of self compatible pollen in a normally self incompatible plant i.e. one whose own pollen is incapable of effecting the fertilisation of its ovules. After irradiation of flower buds of sweet cherry, *Prunus avium*, (a normally self incompatible species) a number of mutations to self compatibility were isolated¹; the stigmas provided the testing mechanism and seeds were evidence of success. This induced mutation is identical with a naturally occurring one but normally the rate of mutation is so low that it is easier to use the techniques of induction. When the mutant has been produced it has then to be incorporated into horticulturally desirable varieties—a procedure taking a number of years, which, in this case, is not yet complete. Another example of an efficient test comes from work on soya beans. This crop has a fairly critical lower temperature below which it will not germinate—a characteristic which limits its cultivation in colder areas. After irradiation, mutants which would germinate at the lower temperatures were found by leaving moistened seeds at the desired temperature and transplanting only those that started to grow².

Many other characters require a much more detailed examination or measurement of individual plants or even the growing of large numbers of plants of each type in replicated trials before differences can be observed. Of such characters, yield is perhaps the most difficult because of the large effect of the environment on it, but many of the quality characters which need a bulk of grain or other plant material for processing could not readily be assessed for each of 10,000 let alone 100,000 plants. Clearly, therefore, it is impracticable to use mutation breeding to improve the yield, as such, of a crop variety. It is possible, of course, that in selecting for other characters it may be found that some of the mutants are in fact higher yielding. The reverse is, however, more commonly true. For example four barley mutants in a number of trials had an average protein content of 15.6 per cent compared with the parental 12.8 per cent but the grain yield of the mutants is reported to be 10–20 per cent lower than the parents so that the total protein production of the mutants is only equal to or very slightly higher than that of the parents³. It may even be that the higher protein contents are merely a reflection of the lesser quantity of grain into which the protein is packed.

The prospective mutation breeder is confronted with a range of mutagens and an almost overwhelming amount of information concerning the interactions of environmental factors with the treatments he may use. In practice however the mutagens may be subdivided into two types: ionising radiations and chemical substances. The ionising radiations may again be subdivided into two: short electromagnetic waves classified as X-rays and gamma rays, and particulate rays, usually neutrons, of various speeds depending on their source and commonly classified as fast or slow (thermal) neutrons. The range of chemicals with mutagenic properties is very large and includes both organic and inorganic substances. For any one type of plant material the mutation rate generally rises with increasing dose but so does the mortality so that for each substance there is an optimum dose at which the number of surviving mutations is a maximum. For the majority of mutagenic substances this maximum rate is much lower than the maximum obtainable with irradiation, but

for a few substances higher rates have been reported. Such substances, which are the ones of interest to the practical breeder, include the nitrogen mustards and certain epoxides, imines and sulphonates all of which are alkylating agents; of these ethylene imine and ethyl methane sulphonate appear particularly promising. Another group of mutagenic substances consists of purines, pyrimidines and alkaloids and includes derivatives of naturally occurring substances; for example nebularine is a component of a fungal nucleic acid. The choice of a suitable mutagen will depend not only on the maximum mutation rate obtainable but also on several other factors including the availability and ease of handling of each agent in relation to the plant material to be treated.

The overall rate of induction of mutations is important. Mutations may, however, be of various kinds so that the spectrum or relative frequencies of individual mutations could also be important. This would be especially so if the purpose of the treatment was to seek a particular mutant form and if the spectra of the various mutagens were widely different. From the early work however it appeared that all treatments produced closely similar results although detailed studies did later reveal that X-rays and neutrons differed slightly in the relative proportions of various mutations. Many chemical mutagens also give a spectrum not clearly distinct from that produced by X-rays but recently substances have been tested which are reported to give different frequencies of particular types of mutation. In the fruit fly, *Drosophila*, it is claimed that the use of alkylating agents results in a whole range of mutants not previously seen using X-rays⁴. With certain micro-organisms the techniques of genetic analysis are so fine that many sites can be recognised as influenced by mutation even within a single gene. These sub-genic sites or " mutons " react in a highly specific way to particular mutagens: some are very susceptible to some mutagens and resistant to others while at other sites moderate mutation rates occur with a number of different mutagens. It seems unlikely however that this specificity at the muton level will appear also at the level of the gene, owing to the large number of mutons in a gene. Furthermore, there is at present no guarantee that it is safe to extrapolate from micro-organisms to crop plants. In passing however it is worth mentioning that induced mutations in micro-organisms may have economic importance in themselves. Indeed the greatly increased production of penicillin by the *Penicillium* fungus has been achieved entirely by mutation breeding, for the fungus has no sexual stage in its life cycle and is thus difficult to improve by methods depending on hybridisation.

Mutagens may be applied to seeds, buds or pollen grains according to the type of plant and the nature of the mutagen itself. Much of the irradiation work has been done with dry seeds since they are so convenient to store and handle, but with some plants, particularly those that are clonally propagated, it would be inappropriate to treat seeds. In such cases cuttings or whole plants have been irradiated or injected with a chemical mutagen. For irradiation of growing plants a radio-active isotope of cobalt which emits gamma rays has proved very useful. This can be set up on a retractable pedestal in a so called " gamma field " so that plants can be grown at an appropriate distance from the source and irradiated for periods varying from days to years. Since a mutation is an event within the nucleus of a single cell and since the growing points of most plants consist of a number of cells, every irradiated bud or seed develops into a " chimera " in which cells carrying different mutations will be

in competition not only with each other but possibly with unmutated cells. It is likely that any cell type with an impaired growth rate will be eliminated during growth and many induced mutations will be lost before they are ever observed. The smaller the original number of cells the less will be the competition and for this reason it is usually easier to extract the mutations from an irradiated seed than from a treated shoot. Techniques for dealing with the shoot have been developed with black currants and involve repeated cutting back to stimulate growth from dormant buds⁵.

The frequency of mutation in plant material is influenced not only by the mutagen but also by a number of environmental factors, especially in the case of seeds for which big variations are possible. These factors include the water content, the oxygen and carbon dioxide tensions, the age and the period of storage after treatment. Some of these factors affect the results with X-ray treatment much more than when neutrons are used. Their interactions with chemical mutagens are largely unknown. The breeder however is not primarily concerned with the effects of these factors provided he can select a suitable mutagen and an appropriate environment for his material so that he consistently obtains high mutation rates and does not kill his plants in the process. Despite the variations in mutation rates and in mutation frequencies the choice of a suitable mutagen still depends largely on practical considerations, such as its availability and ease of application. And in any case the real work of mutation breeding lies not in the production of mutations but in the ability of the breeder to isolate and recognise what will be of value to him.

In order to appreciate the reasons for using mutation breeding and the significance of the practical results so far obtained it is necessary to consider how the techniques appropriate to any crop are related to the breeding system of that crop. For this purpose it is convenient to divide the plant species into those that are self-pollinated, those that are cross-pollinated and those that are propagated commercially by vegetative means. A variety of a self-pollinated crop, such as wheat or barley, is normally true breeding with little or no variation between the individual plants. Before the breeder can select new and possibly improved types of plant he has, therefore, to create variation artificially either by hybridisation or by treatment with a mutagen. In most breeding programmes the problem is to find a balanced genotype well adapted to the stringent environment provided by modern farming and capable of responding to a wide range of climatic and edaphic conditions.

The effect a mutation produces on the plant depends on its genetic background, that is, on the rest of the genes present. When seeds or plants of a variety are exposed to the action of a mutagen, each mutation is tested only against the particular genetic background of that variety. This greatly limits the possibility of producing favourable changes by mutagenic treatments. It is therefore much to the credit of a number of exponents of mutation breeding that they have succeeded in producing marketable forms of barley, peas and beans (*Phaseolus*) despite the strong competition from breeders using hybridisation and selection. Mutations may be placed in several backgrounds either by treating hybrid grain in which case the mutation will be observed in a number of related backgrounds during the segregating generations, or by subsequent hybridisation of mutants with one another or with unrelated lines. It is probable that when a mutation produces several effects, as is commonly the case,

each effect may be altered to a different extent when the background is changed by hybridisation.

If mutation breeding is to be successful with self-pollinated crops it will almost always require to be combined with hybridisation for the production of new varieties. The induction of mutations conferring resistance to diseases has been widely quoted as an example of the value of mutation breeding but this must be examined critically in relation to the known sources of resistance. The technique of back-crossing provides an efficient means of introducing resistance genes into an existing genotype but if the desired type of resistance is unknown it may be worth attempting its induction. This poses the question of whether it is likely that a factor with a selective advantage, such as disease resistance, which does not already exist in a species could be induced artificially. At present there does not seem to be a clear answer to this but that is no reason for not trying to produce the resistance. It should be said that one of the difficulties to be overcome in working with self-pollinating crops is that after irradiation the first generation plants frequently become temporarily pollen sterile and are therefore liable to out-pollination. Subsequent segregates may then be confused with mutants.

Cross-pollinated crops, for example sugar beet or ryegrass, provide a situation quite different from that in a self-pollinated species, because in the former the individual plants of a variety or strain are not even nearly true breeding and are genetically distinct from one another. This implies that genetic differences are naturally available in crops of this sort although sometimes there may not be sufficient for a breeder to achieve his objectives. When these crops set seed the genotype of individual plants is not perpetuated in the next generation and the structure of the population is liable to be altered. If seeds of such a crop are treated with a mutagen, the plants grown from those seeds may contain mutations, but generally the mutations will not be detectable because most display their effects only in individuals which receive the mutant gene through both pollen and egg. In self-pollinating crops the natural system of reproduction will serve to reveal mutations in the next generation. With a cross-pollinated species enforced inbreeding becomes necessary to expose the mutations and will also expose some of the load of recessive genes normally carried in such a species, with inbreeding depression as a result. In practice the mutations may be left just to float in the population in which case they add to its variability and if they are valuable mutations they are likely to find their way into new selections. At every generation they will move into new genetic backgrounds in some of which they may be more useful than in others. In Sweden this technique was used in the production of a strain of white mustard having a higher oil content⁶. Selection for oil content had, for some time, proved ineffective but after irradiation further progress was made. While there is good evidence that this was due to the irradiation it cannot be proved with certainty. An alternative procedure with cross-pollinating crops is to produce lines by deliberate inbreeding, to treat these with mutagens, to isolate useful mutations and then to incorporate them into populations which will subsequently be out-pollinated. It should be observed, however, that the breeders of most out-pollinated crops have ample variability with which to work and are often more concerned in controlling the existing variability than in creating still more. Nevertheless in some crops, such as field beans, there is

a real shortage of desirable variability and in others particular characters are lacking, such as resistance to sugar beet yellows: in situations such as these there is probably a good case for using mutation breeding in out-pollinated crops.

The third group of crops consists of those such as potatoes or strawberries which are propagated vegetatively. The individual plants of a variety are far from true breeding but at the same time they are genetically identical since they have been produced by vegetative propagation and so constitute a clone. The crop can therefore be maintained without genetic change when new plantings are established but the breeder must create variability by hybridisation or the induction of mutations before he can proceed. Owing to the genetic constitution of the plants constituting a variety it is not normally possible, by back-crossing or other systems of hybridisation, to keep the genotype of one parent more or less intact as can be done with self-pollinating crops. This means that if a variety is deficient in some character such as disease resistance, fruit colour or maturity date it is not possible to introduce the missing element by hybridisation while retaining the other characteristics of the variety. By using mutagenic agents such characters can sometimes be introduced into a variety without making large changes in its general performance. It is unlikely that the phenotypic changes will be entirely restricted to one character but the ancillary changes may be small enough to be disregarded. Useful mutations have been produced by irradiation of peach trees with gamma rays from a cobalt 60 source resulting in both earlier and later ripening and in changes in the firmness and texture of the fruit⁷. With black currants encouraging results have also been obtained after treatment with X-rays⁵. The changes brought about include the production of larger berries and an increase in the winter hardiness of the crop—both important characters. The technical difficulties of handling clonally propagated woody crops of this kind are being overcome and it seems that for them, in particular, mutation breeding may have an important future, especially in species which take a long time to reach maturity from seed.

It was stated earlier that mutation breeding must stand or fall by its ability to compete with other methods, but when it can succeed where other methods fail then clearly comparisons become pointless. Radiations, and some chemical mutagens, also, have effects in plant cells, other than causing mutation, which can be turned to good account. In breeding improved crop varieties it is often most desirable to hybridise plants from different species or even different genera in order to introduce some new character from a wild plant into its cultivated relative. Many such crosses cannot be made at all or the rarity of seed setting precludes their use in practice. After irradiation of one of the potential parents however the production of fertile seeds from certain crosses has become much more frequent⁸. However, even when such crosses have been made the breeder's problems are by no means at an end. The cultivated wheat of this country can, for example, be crossed with rye and with certain grasses without recourse to radiation treatments, but although the chromosomes of the two species inhabit the same cell in the hybrid plant there is no exchange of genes between them. If the alien chromosomes are later lost as they may be the wheat variety is unaltered by the temporary association. If however the cells containing both sets of chromosomes are irradiated some of the chromosomes are likely to be broken and when the broken ends are repaired it may

happen that a portion of one of the alien chromosomes becomes attached to a wheat chromosome and a permanent genetic union has been made which, so far, has not been possible by other methods. The first and best known example of this resulted in the transference of leaf rust resistance from the grass *Aegilops umbellulata* to cultivated wheat⁹.

From this brief survey it should be evident that mutation breeding is a technique which has come to stay although it is far from universally applicable to all crops in all situations. Each breeder must make up his own mind whether a particular problem is best tackled through hybridisation or the induction of mutations. To do this he must draw on his previous experience with the crop, his knowledge of the characters concerned and his assessment of the potentialities of the mutation method. It cannot be emphasised too strongly that a gamma field is no alternative to a trained plant breeder. Mutation breeding is now in use in many countries and it seems likely that the best assessment of the method will come from those experienced breeders who, while they continue to use hybridisation, are prepared to try the new techniques. The techniques themselves are by no means finally established and an enormous amount of research into methods of producing mutations is still being done; it may be hoped, therefore, that the techniques available to the breeder will ultimately be much improved. The ideal would undoubtedly be a range of mutagenic treatments which produced not only high total mutation rates but each of which resulted primarily in mutations of a particular kind. This ideal of directed mutations, although still very distant, is no longer quite as unrealistic as it once seemed, now that the varying effects of chemical mutagens have been demonstrated. Newly discovered mutagenic chemicals with increased biological activity have been announced in the last few years and it may well be that we are now on the threshold of fresh advances in the field of mutation breeding.

- ¹ LEWIS, D. 1949. Structure of the incompatibility gene. II. Induced mutation rate. *Heredity*, **3**, 339-355.
- ² ZACHARIAS, M. 1956. Mutationsversuche an Kulturpflanzen VI Röntgenbestrahlungen der Sojabohne. *Züchter*, **26**, 321-338.
- ³ STUBBE, H. 1959. Some results and problems of theoretical and applied mutation research. *Indian J. Genet.*, **19**, 13-29.
- ⁴ FAHMY, O. G. and M. J. FAHMY. 1959. Differential gene response to mutagens in *Drosophila melanogaster*. *Genetics*, **44**, 1149-1171.
- ⁵ BAUER, R. 1957. The induction of vegetative mutations in *Ribes nigrum*. *Hereditas*, **43**, 323-337.
- ⁶ ANDERSSON, G. and G. OLSSON. 1954. Svalöfs Primex white mustard—a market variety selected in X-ray treated material. *Acta Agr. Scand.*, **4**, 574-577.
- ⁷ HOUGH, L. F. and G. M. WEAVER. 1958. Irradiation as an aid in fruit variety improvement. *Proc. X Int. Cong. Genetics*, **2**, 124.
- ⁸ DAVIES, D. R. 1960. Induced mutations in crop plants. *J. Roy. Soc. Arts*, **108**, 596-611.
- ⁹ SEARS, E. R. 1956. The transfer of leaf rust resistance from *Aegilops umbellulata* to wheat. *Brookhaven Symp. Biol.*, **9**, 1-21.

SOIL-BORNE PLANT VIRUSES

INTRODUCTION

The idea that the soil harbours plant viruses may not seem odd to those who are aware of the diversity of soil-borne pathogens, but it is one that has been unfashionable among plant virologists. The reason probably is that it was

discovered early in virus research that plant virus diseases are frequently transferred from plant to plant by insects such as aphids or leafhoppers, which act as carriers of the infective viruses. So many viruses were shown to be carried in this way that it seemed unnecessary to look for other modes of transmission—least of all through soil, where viruses seemed to stand little chance of survival in an infective state. Although some soil-borne virus diseases were discovered, notably the important cereal mosaic diseases in North America, these were regarded as curiosities and their discovery did not disturb the belief that most of those viruses whose mode of spread was still unknown would prove to have aerial insect vectors.

A revival of interest in soil-borne viruses has recently come about because research in several countries has shown that crop plants as diverse as tobacco, potato, raspberry, grape vine and peach, suffer from serious diseases caused by viruses that are transmitted through the soil and have no aerial insect vectors. These discoveries have stimulated a fresh approach to problems of plant virus spread. Whether soil transmission is an important mode of virus spread and whether viruses are transmitted in as great a diversity of ways below as above ground, it is much too early to say. Indeed we are still far from understanding the biology of the soil-borne viruses so far discovered, still less how best to control them. With the object of bettering this understanding and of establishing perspectives in a rapidly developing field of work, a symposium on soil-borne viruses, sponsored by the Agricultural Research Council and attended by representative workers from Britain and overseas countries, was recently held in Scotland. The purpose of this short review is to outline the present state of knowledge on the subject.

Contact between the roots of diseased and healthy plants in soil perhaps accounts for the spread of some kinds of plant viruses—potato virus X for instance—but the term “soil-borne” usually denotes viruses that have some natural method of spread in soil that is independent of contact between the tissues of diseased and healthy plants. Differences in methods of spread of the known soil-borne viruses provide a means of separating them into three categories. These are (a) viruses whose spread appears to be independent of soil-living organisms, (b) viruses transmitted by soil-inhabiting agents other than nematodes (eelworms) and (c) viruses transmitted by ectoparasitic nematodes (eelworms feeding on the outsides of roots). This classification is purely one of convenience. It is akin to lumping insect-borne viruses into groups according to whether they are transmitted by leaf-hoppers, aphids, or other kinds of insects and implies no other common character within each group.

VIRUSES SPREADING INDEPENDENTLY OF SOIL ORGANISMS

This group includes tobacco mosaic and the various tobacco necrosis viruses, all of which are very stable and highly infectious. Indeed, it is perhaps because of these properties that the methods of transmission of these viruses through soil are still obscure.

Contact between the foliage of diseased and healthy plants or with the contaminated hands or implements of workers probably accounts for some of the spread of tobacco mosaic virus in glasshouse tomato crops or in tobacco crops in the field. But it seems possible that the virus may have some natural

underground method of spread because it often occurs in the roots of naturally infected weed plants, and sometimes in those of cultivated plants too—for example, strawberry. Plants become infected when grown in soil to which infective plant debris or sap has been added and there is evidence that the virus can persist in an infective state in soils, absorbed to colloidal material. The relevance of these facts to the infection process is uncertain, however, and if plants do become infected with tobacco mosaic virus from the soil by a mechanical process its details are still unknown.

The name tobacco necrosis was first given to a virus found infecting the roots of tobacco plants in glasshouses at Cambridge, and which caused necrotic lesions in inoculated tobacco and French bean leaves. It was later applied to other viruses possessing biological and physical properties similar to those of the Cambridge virus, but serologically unrelated to it, and now the name is used in a loose sense to denote a large group of viruses of world-wide distribution, some of which share little other than their physical properties and soil-borne nature with the “classical” type of tobacco necrosis virus. Most kinds of tobacco necrosis virus (in this broad sense) remain localised in the roots of infected plants and seem of no economic importance. Other kinds or strains cause systemic necrotic diseases of tulips, cucumber, and runner beans in the Netherlands, and of cucumber in Canada, and have been isolated from systemically infected weed plants in Britain.

Like tobacco mosaic virus, these tobacco necrosis viruses have wide host ranges, are very stable and highly infectious, and persist for long periods in soil when added as infective sap or plant debris. Other observations suggest that the viruses are not transmissible through soil solely by mechanical means. For example, although the viruses are adsorbed by soil colloids and can often be detected in the colloidal fraction of fields soil, plants often fail to become infected when grown in such virus-containing soils. Under glass, plants become naturally infected more often in winter than in summer, and from the Netherlands there is some evidence of host specificity among strains or kinds of tobacco necrosis viruses: thus, potatoes escaped infection when grown in fields where beans and tulips always became infected and *vice versa*.

VIRUSES TRANSMITTED BY ORGANISMS OTHER THAN NEMATODES

The viruses in this group include the North American soil-borne wheat and oat mosaic viruses and tobacco stunt, a virus affecting tobacco in Japan.

In economic importance, soil-borne wheat mosaic dwarfs all other soil-borne virus diseases. The soils of immense areas of eastern and central United States are infected—one million acres in Kansas alone, where the estimated loss of crop in a recent epidemic was four million bushels. Unlike most other soil-borne viruses, the wheat and oat mosaic viruses have narrow host ranges, restricted to members of the Gramineae. They are difficult to transmit mechanically in sap, and although as stable as many other kinds of plant virus, there is little critical information on their properties or on the relationship either between the various strains of the two viruses that have been described or between these and other similar viruses affecting cereal crops.

These viruses have been the subject of pioneer work in the United States by McKinney and his associates since the early 1920's. Some kind of soil-living organism is probably concerned in transmission but so far none has been

identified. Soils retain infectivity for long periods when dried but can be disinfested by steam sterilisation or treatment with various chemicals. The viruses can be maintained in an infective condition in media such as glass beads or sterilised river sand to which only the washed roots of naturally infected plants have been added; also healthy wheat seedlings become infected with wheat mosaic virus when exposed in dishes of water that have contained the roots of naturally infected plants.

Unfortunately, active research on this fascinating problem is lapsing because of the successful control of the viruses through the production of immune varieties of cereals.

Soil-borne virus diseases of wheat and barley resembling those in the United States occur also in Japan but there is nothing to show that the viruses themselves are related. A recent claim that Japanese wheat yellow mosaic virus is transmitted mechanically through the soil is difficult to assess. No diseases resembling the North American ones have yet been reported from Europe.

Tobacco stunt is a severe virus disease contracted by tobacco plants, chiefly in the seedling stage, from materials used to make seed beds in Japan. Soils retain infectivity for long periods when dried, but can be freed from virus by treatment with steam or various chemicals. Like the soil-borne cereal viruses, tobacco stunt has a restricted host range: tobacco is the only known host and the virus is transmissible only by grafting. The roots of diseased plants are invariably colonised by the Chytrid fungus, *Olpidium brassicae*, and because soil treatments eliminating the fungus also eliminate the disease, it is believed that the fungus may be a vector. Critical evidence for this has not yet been obtained, though it is known that tobacco plants attacked by "virus-free" cultures of the fungus develop symptoms different from those of tobacco stunt disease.

VIRUSES TRANSMITTED BY NEMATODES

Because many kinds of eelworms feed on plant roots they might seem well fitted to act as vectors of plant viruses, but evidence that they do is of very recent origin. It was only in 1958 that Dr. W. B. Hewitt and his colleagues announced that fanleaf disease of grape vine in California was soil-borne and had a nematode as a vector, and since then nematode vectors for at least four other soil-borne viruses have been found. The nematodes themselves belong to rather closely related groups, but none was previously known to feed on living plants although all seem well equipped to do so. They have long mouth spears and feed by piercing plant tissues and sucking out the cell contents. Little is yet known about the ecology and behaviour of these nematodes in soils but they transmit viruses causing serious diseases in a wide range of crop plants.

The viruses fall into two groups: those related to tobacco rattle virus, and those of the ringspot type.

Tobacco Rattle Virus

The name "stripe and curl" disease, which was formerly used, aptly describes the effects of this virus in tobacco plants—mainly discoloured streaks on the stems and curling of the leaves. The soil-borne nature of the disease was

suspected as long ago as 1899 but it took another thirty years to discover that the cause was a soil-borne virus. The name tobacco rattle virus dates only from 1943, when the properties of the virus were first adequately described by Quanjer in the Netherlands. Since then the virus has been found in many European countries, in Britain and in several parts of North America. It seems one of the commonest soil-borne viruses to occur in light sandy or peaty soils and is most familiar as the cause of disfiguring necrotic diseases in potato tubers—spraing and corky ringspot—and as a disease of potato haulms—potato stem mottle. The virus also commonly infects tulip and narcissus, in which it causes leaf striping, flower breaking and poor growth. But tobacco rattle virus has an extraordinarily wide host range: it has been transmitted experimentally to over 400 species of plants and has been found naturally infecting at least 100 others.

Tobacco rattle virus possesses several rather unusual properties. Forms of the virus commonly associated with severe diseases in plants are usually extremely difficult to transmit by mechanical inoculation of sap. For example, it is very difficult to transmit the stem mottle disease of potato haulms, in which symptoms are usually severe. On the other hand, there are diseases with very much milder symptoms in which the virus reaches relatively high concentration and which are readily sap transmissible. The forms producing severe symptoms often arise as variants from those causing mild symptoms. Infective sap characteristically contains a mixture of long and short rod-shaped particles but only the long particles are infective. These phenomena are still unexplained.

Indirect evidence that tobacco rattle virus has a nematode vector has been obtained by several workers in Europe; this has been confirmed recently in the Netherlands, in that the virus has been transmitted experimentally by means of a nematode identified as *Trichodorus pachydermus*.

Soil-borne Ringspot Viruses

The name "ringspot" is used here to describe viruses which resemble tobacco ringspot virus in many of their properties. Like tobacco rattle virus, the soil-borne ringspot viruses infect a whole range of herbaceous and woody plants and seem to occur widely in soils in Britain and other parts of Europe and in North America. So far, four viruses have been discovered; these are named arabis mosaic, raspberry ringspot, tomato black ring and tomato ringspot viruses. They are serologically unrelated but all possess rather similar biological and physical properties. All have small "spherical" particles about 300 Å diameter, and at least three and possibly all of them are transmitted by ectoparasitic nematodes.

Host range, variability and vectors of ringspot viruses. Because of their wide host ranges, most of the soil-borne ringspot viruses have been given a variety of different names when isolated from different hosts in different countries. Much of the resulting confusion has been clarified and some interesting relationships between viruses and virus diseases revealed by the application of serological techniques. Thus, arabis mosaic virus, for long known only as a curiosity in a glasshouse plant, causes severe diseases of raspberry and strawberry in Britain and also a mosaic disease of rhubarb in Germany, whilst related strains of the virus cause fan leaf disease of grape vine in Europe and

California. Other hosts found naturally infected are elderberry, horse-radish, sweet cherry, cucumber and privet. Raspberry ringspot virus is the cause of severe diseases in many varieties of raspberry and strawberry in Scotland and is associated with severe diseases of the "rasp-leaf" type in sweet cherry in England, Germany, Switzerland and the Netherlands. Tomato black ring virus, first described from tomato in England, is widespread and infects many kinds of crop plants, including raspberry and strawberry in Scotland, and potato in Germany. Serological work has shown recently that peach yellow bud mosaic, a virus that causes a disease of peaches in California and is spread by nematodes, is really a strain of tomato ringspot, a North American virus with a wide host range whose method of spread was formerly unknown.

Variation is another feature of these viruses which seems in some way related to their wide host and territorial ranges. For example, the strains of arabis mosaic virus that have been isolated from raspberry, strawberry, cherry, rhubarb and several other kinds of herbaceous or shrubby plants in different parts of Europe are all rather closely related serologically, although it is just possible to detect differences between isolates whose sources are geographically far apart. Some, and probably all these strains have a dagger nematode, *Xiphinema diversicaudatum*, as a vector. Strains of the virus isolated from grape vine in Europe are serologically distinguishable from those that occur in vine in California. The Californian and probably also the European grapevine strains are transmitted by another species of *Xiphinema*, *X. index*, and as a group, the grape vine strains are only distantly related to other strains of arabis mosaic virus. One interpretation is that the differences between groups of virus strains reflect some kind of ecological relationship between host, nematode and virus, and that differentiations within groups result from the limited opportunities these viruses have of spreading over long distances.

Raspberry ringspot and tomato black ring viruses often occur together in soils, at least in Scotland. Both viruses show much more geographical variation than does arabis mosaic virus. Continental strains appear to be more closely related serologically with English than with Scottish strains of the viruses. Isolates from individual regions, such as eastern Scotland, on the other hand, are usually indistinguishable serologically from one another. *Longidorus elongatus*, a relative of *Xiphinema*, is concerned in the transmission of tomato black ring virus but its precise role is still obscure. The transmission of raspberry ringspot virus also, is almost certainly associated with nematodes.

Another species of *Xiphinema*, *X. americanum*, is associated with the transmission of tomato ringspot virus to peach in California; this nematode occurs widely in North America and also in Europe. So far, tomato ringspot virus has not been found in Europe and too few isolates from North America have been studied to know to what extent it shows geographical variation.

Dissemination of ringspot viruses. It seems characteristic of the soil-borne ringspot viruses, and of tobacco rattle virus too, that, widespread though they are, their distribution is localised, indeed often restricted to patches in particular fields. Outbreaks of the diseases they cause recur whenever such fields are planted with susceptible crops. In outbreaks of diseases caused by arabis mosaic virus, the distribution of diseased plants is rather closely correlated with the presence of *Xiphinema* in the soil and the same seems true of tomato

black ring virus and the nematode *Longidorus*, so that, possibly, localisation of the virus reflects the action of ecological factors, still unknown, on the activities of the nematodes. Even within individual fields, virus spread seems little influenced by tillage because patches of infection remain static for long periods.

The ability of the viruses to infect and the nematodes to feed on a wide range of crop and weed plants ensures the persistence of the viruses in infected soils. Experiments with *Xiphinema index* and *X. diversicaudatum* suggest that nematodes which have acquired arabis mosaic virus by feeding on infected plants remain able to transmit virus to healthy plants for some weeks or even months. But it is most unlikely that arabis mosaic or indeed any of the other viruses in this group, including tobacco rattle virus, are spread far by their vectors because the nematodes die when soil containing them becomes dry enough for carriage by wind.

The viruses themselves have a highly efficient means of dispersal because all are seed-borne in many of their hosts, including common weed plants like groundsel, chickweed and shepherd's purse. Moreover, seeds from infected plants produce progeny which grow and reproduce normally although a high proportion may be systemically infected by virus. Clearly then, all that seems necessary for the establishment of new foci of infection in soils is the germination of infected weed seeds in land already containing the appropriate nematode vector. The same result would ensue from the use of infected planting material that has been vegetatively propagated. For example, tomato black ring virus became established in a soil, initially free from virus but which contained *Longidorus elongatus*, when infected potato plants were grown in it. As the viruses are disseminated by such easy means, one might reasonably expect them to occur oftener in soils than they appear to do; the reason they do not may lie in aspects of the biology of soils and nematodes of which we are still almost totally ignorant.

Control of ringspot viruses. Such lack of knowledge is also a hindrance in any approach to the control of this group of soil-borne viruses. It seems clear that the viruses are as much pathogens of wild as of cultivated plants, and hence that crop rotation is of little avail as a means of control. Perhaps, however, there may be ways in which the balance between nematode, virus and host plant can be altered. Nothing is known of the host preferences of the nematodes or of the role of dormant infected weed seeds as a means of perennation for the viruses.

Although the nematodes can be destroyed and infectivity abolished by treating small quantities of infective soils with nematicides, or even with chemicals normally used as soil fungicides, such as pentachloronitrobenzene and tetramethylthiuramdisulphide, such chemical treatments seem unlikely to succeed in the field. This is because of the difficulty of treating soils to the depths to which the nematodes are able to migrate. Possibly chemical control may prove worthwhile on valuable land planted with relatively short-lived crops such as strawberry, but not with perennial crops such as raspberry, grape vine or cherry.

With these the remedy would seem to lie in breeding varieties or understocks that resist or are immune from infection by the viruses, or are unpalatable to the nematodes. In raspberry, and possibly also strawberry, there is evidence

that some varieties are immune from infection by one or more of the soil-borne ringspot viruses that occur in Britain. Such varieties fail to become infected either when grafted with virus-containing scions or when grown in infective soils in the field.

CONCLUSION

Broadly speaking, soil-borne viruses are no more than local nuisances in crops, though naturally their nuisance value is greater in long-lived and costly crops such as cherry and grape vine. The position is very different, however, when the viruses occur in land used for the propagation of healthy plants. Not only does their presence in soils usually pass undetected until the land is planted with a susceptible crop, but the viruses enter plant roots and multiply there long before symptoms show in the foliage. This presents a special difficulty in the operation of plant health schemes, because plants certified and distributed in good faith as apparently healthy may later become diseased and, worse still, provide means of introducing the viruses to new areas.

The rate at which developments have occurred in the study of soil-borne plant viruses in the last few years has surprised even those most closely associated with them. Already much fresh light has been shed on old problems and new ones press for investigation. To gain a proper understanding of the role of nematodes as virus vectors will certainly demand more knowledge of nematode behaviour in soils. If the present impetus in the investigation of soil-borne viruses continues, therefore, the discovery of new methods of virus transmission through soil may have repercussions in other fields of soil microbiology. The soil is something one tends to take for granted as a convenient medium in which to grow plants. It is only when one has cause to probe into it that the intricate nature of the relationships of its inhabitants becomes apparent.

RESEARCH STUDENTSHIPS AND FELLOWSHIPS

(a) RESEARCH STUDENTSHIPS

These studentships are intended to enable young graduates who wish to make a career in agricultural research either to take a further course of study or to undertake a specific research project under supervision as a means of training in research methods, or to read for a veterinary degree in order to equip themselves for research in fields in which this added qualification is likely to be of particular advantage. They are open to honours graduates in science or those holding a veterinary qualification and to graduates in agriculture or horticulture who have shown special interest in one of the basic sciences.

The following twenty-two awards were made in 1959:—

<i>Name</i>	<i>Place of Tenure</i>	<i>Subject</i>
D. H. L. Bishop ...	Liverpool University ...	Biochemistry
Miss F. M. Bull ...	Rothamsted Experimental Station ...	Entomology
Miss B. D. Dawson	Cambridge University ...	Parasitology
H. J. Duncan ...	Glasgow University ...	Plant Biochemistry
D. O. Gray ...	London University ...	Plant Biochemistry
J. Hill ...	Birmingham University ...	Biometrical Genetics
J. M. Hopkinson...	Nottingham University...	Plant Physiology
J. M. Jewsbury ...	London University ...	Parasitology
R. B. Knox ...	Queen's University, Belfast ...	Plant Breeding
J. Lacey ...	Rothamsted Experimental Station ...	Plant Pathology
B. F. Leek ...	Edinburgh University ...	Animal Physiology
D. K. Lewis ...	Bristol University ...	Biochemistry of Micro-organisms
R. J. Rowbury ...	Oxford University ...	Microbiological Chemistry
Miss S. J. Skews ...	London University ...	Plant Physiology
A. G. Smithers ...	London University ...	Plant Physiology
M. J. C. Rhodes ...	Bristol University ...	Plant Biochemistry
G. H. L. Rothschild	London University ...	Entomology
W. S. Tallack ...	Rothamsted Experimental Station ...	Entomology
J. P. Thornber ...	Cambridge University ...	Plant Biochemistry
P. W. Trudgill ...	Leeds University ...	Biochemistry
A. Winter ...	University College, Swansea ...	Plant Physiology
D. J. R. Manley ...	Aberdeen University ...	Soil Science

At 31st March, 1960, the number of students in training was 64, divided amongst the different disciplines as follows:—

<i>Botany</i>	<i>Chemistry</i>	<i>Entomology</i>	<i>Statistics</i>	<i>Zoology and Veterinary Science</i>
22	16	10	1	15

(b) FELLOWSHIPS

Up to three Agricultural Research Fellowships, tenable for a maximum period of three years, are available annually.

Veterinary Research Fellowships, tenable for three years, are available to veterinary graduates with not less than three years' post-graduate experience who wish to continue their researches for a further period before seeking a post. No awards were made during the year under review.

SPECIAL RESEARCH GRANTS

During the period covered by this Report the Council has continued to make grants to Universities, Colleges and other organisations, to assist in research projects on subjects of interest to the Council. Grants are normally limited to three years but occasionally they are made for longer periods.

The grants current on 31st March, 1960, were as follows:—

1. ABERDEEN UNIVERSITY

Department of Soil Science

Investigation of the chemistry of soil organic matter.

2. ABERYSTWYTH, UNIVERSITY COLLEGE OF WALES

(i) *Department of Agricultural Botany*

A comparative biochemical assessment of specific genotypes of herbage grasses in relation to their physiological characteristics.

(ii) *Department of Agricultural Chemistry*

The biosynthesis of thiamine in micro-organisms.

3. BANGOR, UNIVERSITY COLLEGE OF NORTH WALES

(i) *Department of Agricultural Botany*

The adaption of wild white clover to upland conditions.

(ii) *Department of Agricultural Chemistry*

(a) The metabolism of herbicides by soil bacteria.

(b) The biochemical and nutritive properties of pasture plants (A long-term grant).

(c) The metabolism of synthetic oestrogens and the derivatives by soil micro-organisms.

4. BIRMINGHAM UNIVERSITY

Department of Botany

A taxonomic investigation of the tuber-bearing species of *Solanum*, using serological and other techniques.

5. BRISTOL UNIVERSITY

(i) *Department of Animal Husbandry*

The nutrition of the baby pig.

(ii) *Department of Physiology*

Research on bovine acetoanaemia.

(iii) *Department of Veterinary Medicine*

The experimental transmission of lymphoid leukaemia.

6. CAMBRIDGE UNIVERSITY

(i) *School of Agriculture*

- (a) The carcass quality of beef. (A long-term grant.)
- (b) Protein quality in human foods and animal feeding stuffs.
- (c) Studies of poultry genetics employing inbred lines.
- (d) A study of soil-borne plant pathogenic fungi.
- (e) The mycological aspects of cellulose decomposition of soils.

(ii) *Department of Animal Pathology*

Research on respiratory diseases in poultry. (A long-term grant.)

(iii) *Department of Biochemistry*

- (a) The biochemistry of the uterus.
- (b) The biochemistry of chloroplasts in relation to photosynthetic phosphorylation.
- (c) The organisation and chemical composition of plant cell walls during growth.
- (d) The biochemical synthesis of plant cell wall constituents.

(iv) *School of Botany*

The growth and form of an annual plant as a function of environmental conditions.

(v) *Department of Colloid Science*

The surface properties of cells.

(vi) *Department of Pathology*

Immunological and serological research. (A block grant made jointly with the Nuffield Foundation.)

(vii) *School of Veterinary Medicine*

- (a) The sow's mammary gland in health and disease.
- (b) Research on piglet mortality with particular reference to transmissible gastro-enteritis. (A long-term grant.)

(viii) *Department of Veterinary Clinical Studies*

- (a) Blood groups of the pig. (A long-term grant.)
- (b) Climatic conditions in "broiler" chicken houses.
- (c) The physiological basis of neonatal mortality among animals. (A long-term grant.)
- (d) Research on pyelonephritis in pigs.

7. DURHAM UNIVERSITY (KING'S COLLEGE, NEWCASTLE-UPON-TYNE)

(i) *School of Agriculture*

- (a) Studies of pig farrowing accommodation. (A long-term grant.)
- (b) The progeny testing of cattle for meat and milk production.
- (c) The restoration of opencast coal sites.
- (d) The biology and ecology of frit fly in Northumberland.

(ii) *Department of Chemistry*

The mechanism of melanin formation.

(iii) *Department of Zoology*

A comparative study of the cytology of the genus *Heterodera*.

8. EDINBURGH UNIVERSITY

(i) *Departments of Agriculture and Chemistry*

Research on grass conservation.

(ii) *Department of Animal Genetics*

(a) The genetics of beef and milk production in dual purpose cattle.

(b) Fertilisation and early embryonic development in animals.

(iii) *Department of Biochemistry*

The metabolism of radio iron in immature pullets and laying hens.

(iv) *Department of Zoology*

Research on insect cell culture.

9. GLASGOW UNIVERSITY

(i) *Department of Bacteriology*

Research on aerobic spore-forming bacteria pathogenic for Lepidoptera.

(ii) *Department of Genetics*

The genetics of hydrolases.

(iii) *Department of Veterinary Medicine*

(a) The pathology of pneumonia in pigs.

(b) Electrolyte and body fluid changes in calf diarrhoea.

(c) A study of bovine brucellosis in the field.

(d) The urinary changes associated with electrolyte changes in body fluids.

(e) Immunological studies of young domestic animals.

10. HANNAH DAIRY RESEARCH INSTITUTE

The value of selenium in animal production.

11. HARPER ADAMS AGRICULTURAL COLLEGE

(a) Pig husbandry investigations.

(b) Poultry husbandry investigations.

12. HOUGHTON POULTRY RESEARCH STATION

Avian physiology.

13. LEEDS UNIVERSITY

(i) *Department of Agriculture*

- (a) The nutrition of the pregnant sow.
- (b) Research on clover rot.

(ii) *Department of Biomolecular Structure*

Interpretation of fibre types in sheep.

(iii) *Department of Textile Industries*

The constitution of insect and plant waxes.

14. LIVERPOOL UNIVERSITY

(i) *Department of Veterinary Anatomy*

The nervous and vascular mechanisms involved in semen production.

(ii) *Department of Veterinary Pathology*

Research on the pathogenesis of fowl typhoid.

(iii) *Department of Veterinary Preventive Medicine*

- (a) Research on respiratory diseases in poultry. (A block grant.)
- (b) Serological studies of lung worm infection in farm animals.
- (c) The housing and maintenance of the Reaseheath P line.

(iv) *Department of Tropical Medicine*

Research on the host responses of turkeys and chickens to protozoa.

15. LONDON UNIVERSITY

BIRKBECK COLLEGE

Department of Physics

The molecular structure of viruses.

IMPERIAL COLLEGE OF SCIENCE AND TECHNOLOGY

(i) *Department of Botany and Plant Technology*

The metabolism of oat seedlings.

(ii) *Department of Chemistry*

The fixation of molecular nitrogen by micro-organisms.

(iii) *Department of Zoology and Applied Entomology*

Research on insect ecology. (A five-year block grant.)

KING'S COLLEGE

(i) *Department of Botany*

Research into amino acid biosynthesis and transmethylation in plants.

(ii) *Department of Zoology*

- (a) Studies of *Fasciola hepatica* and other trematodes.
- (b) Research on tick and other arthropod-borne diseases.

LISTER INSTITUTE OF PREVENTIVE MEDICINE

Department of Biochemistry

The mechanism of starch-carbohydrase action.

QUEEN MARY COLLEGE

Department of Botany

(a) Research on photosynthesis.

(b) The effect of carbon dioxide on reactions of isolated chloroplasts.

ROYAL VETERINARY COLLEGE

(a) The relation between climatic environment and productivity in poultry.

(b) Gustatory senses in cattle.

UNIVERSITY COLLEGE

Department of Botany

The metabolism of certain newer amino and imino acids by soil micro-organisms.

UNIVERSITY COLLEGE HOSPITAL MEDICAL SCHOOL

(a) Research on biliary secretions in the rabbit.

(b) Comparative study of susceptibility to drugs and toxic agents in new born animals.

WYE COLLEGE

(a) Research on pig breeding. (A long-term grant.)

(b) Poultry research. (A long-term grant.)

(c) The effects of water and nitrogen on the growth of apple trees.

16. LONG ASHTON RESEARCH STATION

Research on black currant gall mite.

17. NATIONAL VEGETABLE RESEARCH STATION

The effect of sub-lethal doses of herbicides on vegetable crops.

18. NORTH OF SCOTLAND COLLEGE OF AGRICULTURE

The control of gangrene, blackleg and soft rot in potatoes.

19. NOTTINGHAM UNIVERSITY

(i) *School of Agriculture*

(a) Research on oestrogen metabolism in sheep and cattle.

(b) Studies in poultry nutrition.

(c) The development of buds of the potato tuber.

(d) The growth and development of the potato plant in relation to crop production techniques.

(ii) *Department of Horticulture*

- (a) The diagnosis of damage from spray drift.
- (b) Methods of controlling the responses of plants to environmental conditions.
- (c) The water relations of tomato plants grown in heated glasshouses—with special reference to methods of controlling irrigation.

20. OXFORD UNIVERSITY

(i) *Department of Agriculture*

- (a) Isotopic studies of root uptake from the soil and culture solutions.
- (b) The pattern of uptake of growth regulators by higher plants.

(ii) *Department of Botany*

Ability of plant nuclei to respire.

(iii) *Unit of Biometry*

Employment of statistician on problems arising from research in progress at the A.R.C. Radiobiological Laboratory.

(iv) *Department of Pharmacology*

Plasma enzymes in the ruminant.

21. READING UNIVERSITY

(i) *Department of Agriculture*

- (a) Poultry husbandry investigations. (A long-term grant.)
- (b) The use of grazing control in intensive systems of fat lamb production.
- (c) Research on grassland irrigation.

(ii) *Department of Agricultural Botany*

- (a) The physiological and ecological aspects of crop growth.
- (b) Water relations of vegetation on chalk grassland.

(iii) *Department of Horticulture*

- (a) The effect of external conditions on the developmental physiology of the carnation.
- (b) The effect on plant growth and development of wave length of light.

22. ROTHAMSTED EXPERIMENTAL STATION

- (a) Insecticide investigations. (The money for this grant is provided by the Colonial Office.)
- (b) The rental and maintenance of the electronic computer in the Statistical Department.
- (c) Nutrition of forest trees in nurseries. (The money for this grant is provided by the Forestry Commission.)
- (d) Pyrethrum research. (The money for this grant is provided by the D.S.I.R.)

23. ROWETT RESEARCH INSTITUTE

- (a) The absorption and elimination of natural and radioactive isotopes of calcium, strontium and barium in sheep.
- (b) Tests on protein in feedingstuffs.

24. SHEFFIELD UNIVERSITY

(i) *Department of Bacteriology*

Research on toxoplasma infection in relation to bovine abortion.

(ii) *Department of Microbiology (A.R.C. Unit of Microbiology)*

The growth of micro-organisms.

(iii) *Department of Zoology*

Research on comparative endocrinology. (A long-term grant.)

25. SWANSEA, UNIVERSITY COLLEGE

Department of Botany

(a) Studies of the organic and inorganic nutrients in *Eriophorum vaginatum*.

(b) A study of the resting bodies formed by various species of *Verticillium*.

26. A.R.C. RADIOBIOLOGICAL LABORATORY

An investigation of the use of oxygen 15 in plant physiological studies.

27. WEST OF SCOTLAND AGRICULTURAL COLLEGE

Pig farrowing house experiments.

28. OTHER ORGANISATIONS AND INDIVIDUALS

(i) *Electrical Research Association*

(a) Crop conservation and storage.

(b) Farm machinery and equipment.

(c) Electricity in livestock husbandry.

(d) Electricity in horticulture.

(e) Specialised applications of electricity.

(ii) *Kesteven Farm Institute*

Research on broiler nutrition.

(iii) *Ministry of Agriculture, Fisheries and Food*

Research on a continuous field drain-laying machine.

(iv) *Ministry of Agriculture, Fisheries and Food Private Centres A.I. Group*

Infertility in cattle.

(v) *Research Contract with the Printing Packaging and Allied Trades Research Association*

Investigation of horticultural packages.

(vi) *The Lord Rothschild, G.M., Sc.D., F.R.S.*

The physiology and ultra structure of spermatozoa. (A five-year block grant.)

(vii) *Professor A. C. Chibnall, M.A., Sc.D., Ph.D., F.R.S.*

The constitution of plant and insect waxes.

SOIL

ROTHAMSTED EXPERIMENTAL STATION

Harpenden, Herts.

Director: F. C. BAWDEN, M.A., F.R.S.

Deputy Directors: A. Muir, PH.D.
F. Yates, SC.D., F.R.S.

PHYSICS

Head of Department: H. L. Penman,
M.SC., PH.D., F.INST.P.

G. H. Cashen, M.SC.
J. L. Monteith, B.SC., PH.D., D.I.C., A.INST.P.

PEDOLOGY

Head of Department: A. Muir, PH.D.

C. Bloomfield, PH.D., F.R.I.C.
G. Brown, B.SC.
R. Greene-Kelly, PH.D.
J. H. Rayner, B.SC., PH.D.
I. Stephen, B.SC., PH.D.

SOIL MICROBIOLOGY

Head of Department: P. S. Nutman,
B.SC., PH.D., A.R.C.S.

R. M. Jackson, B.SC., PH.D.
Mrs. Janina Kleczkowska, PH.D.
Jane Meiklejohn, PH.D.
F. A. Skinner, M.A., PH.D.
N. Walker, PH.D., F.R.I.C.

BIOCHEMISTRY

Head of Department: N. W. Pirie,
M.A., F.R.S.

A. J. Clarke, B.SC., PH.D.
G. N. Festenstein, M.SC., PH.D.
Margaret Holden, B.SC.
R. H. Kenten, B.SC.
P. J. G. Mann, B.SC., PH.D.
W. S. Pierpoint, B.SC., PH.D.

CHEMISTRY

Head of Department: G. W. Cooke,
PH.D., F.R.I.C.

P. W. Arnold, M.A., B.SC., PH.D., A.R.I.C.
J. K. R. Gasser, M.SC., A.R.I.C.
Signe G. Heintze, M.PHIL.
D. S. Jenkinson, B.A., PH.D.
G. E. G. Mattingly, PH.D.
A. C. D. Newman, B.A., D.PHIL.
T. Z. Nowakowski, PH.D.
O. Talibudeen, M.SC., PH.D.
R. G. Warren, B.SC.
F. V. Widdowson, B.SC.(AGRIC.)

TROPICAL SOILS ADVISER
H. Greene, D.SC.

BOTANY

Head of Department: D. J. Watson, PH.D.

E. C. Humphries, D.SC.
Gillian N. Thorne, B.A., PH.D.
Joan M. Thurston, B.SC.

PLANT PATHOLOGY

Head of Department: P. H. Gregory,
D.SC., D.I.C.

E. W. Buxton, B.SC., PH.D.
Mary D. Glynnne, O.B.E., D.SC.
B. D. Harrison, B.SC., PH.D.
J. M. Hirst, D.S.C., B.SC., PH.D.
B. Kassanis, D.SC.
A. Kleczkowski, M.D., PH.D.
I. Macfarlane, B.SC., PH.D.
H. L. Nixon, M.A.
G. A. Salt, M.A., PH.D.
Mrs. Marion A. Watson, PH.D.

NEMATOLOGY

Head of Department: F. G. W. Jones, M.A.

C. C. Doncaster, B.SC.
Mary T. Franklin, PH.D.
J. B. Goodey, PH.D.
Audrey Shepherd, B.SC., PH.D.
H. R. Wallace, PH.D.
R. D. Winslow, B.AGR., PH.D.

ENTOMOLOGY

Head of Department: K. Mellanby,
C.B.E., B.A., SC.D., PH.D.

C. J. Banks, PH.D.
C. A. T. Edwards, M.SC., PH.D.
G. W. Heath, PH.D.
C. G. Johnson, D.SC.
F. Raw, PH.D.
L. R. Taylor, B.SC.

STATISTICS

Head of Department: F. Yates, SC.D., F.R.S.

D. A. Boyd, PH.D.
B. M. Church, B.SC.
J. C. Gower, M.A.
M. J. R. Healy, B.A.
F. B. Leech, B.AGR., M.R.C.V.S.
W. J. Lessells, B.SC.(ECON.)
H. D. Patterson, M.SC.
D. H. Rees, B.SC.
H. R. Simpson, M.A.

DUNHOLME FIELD STATION

Head of Station: R. Hull, PH.D.

S. N. Adams, D.PHIL.

R. A. Dunning, PH.D.

G. D. Heathcote, PH.D.

BEE RESEARCH

Head of Department: C. G. Butler, PH.D.

L. Bailey, M.A., PH.D.

J. B. Free, M.A., PH.D.

J. Simpson, M.A., PH.D.

INSECTICIDES AND FUNGICIDES

Head of Department: C. Potter, D.SC., D.I.C.

P. E. Burt, B.A.

M. Elliott, PH.D.

F. T. Last, PH.D., D.I.C., A.R.C.S.

K. A. Lord, M.A., PH.D., A.R.I.C.

A. H. McIntosh, PH.D.

R. M. Sawicki, B.SC., PH.D.

M. J. Way, M.A.

FIELD EXPERIMENTS

Head of Section: G. V. Dyke, M.A.

H. V. Garner, O.B.E., M.A., B.SC.

ROTHAMSTED AND WOBURN FARMS

Head of Farms: J. R. Moffatt,

B.SC.(AGRIC.), N.D.A., A.I.AGR.E.

Secretary: J. B. Bennett, F.C.A.

Librarian: D. H. Boalch, M.A., F.S.A.

On 31st March, 1960, the scientific and experimental staff of the Station numbered one hundred and sixty-two.

CURRENT WORK

The many lines of research followed at Rothamsted are described in the Annual Report of the Station for 1959. Those mentioned here indicate only partially the range of subjects covered

Soils and Fertilizers. Investigations of soil and fertilizer nitrogen include attempts to find a chemical measurer of nitrogen requirement; studies of rates of release from organic matter, movement in the soil, and losses by leaching and denitrification; the fixation of nitrogen, both by free-living bacteria and by the nodule-forming symbionts of legumes; comparisons of different forms of nitrogenous fertilizers; and the effects of fertilizers on forms of nitrogen in grass—this last an important topic in relation to animal nutrition. Experiments to test Russian claims that inoculation of soil with certain bacteria increases crop yield have given inconsistent results and are being continued to find out why.

The availability of soil phosphate and the building up of reserves by phosphatic fertilizers are studied by using radioactive phosphorus as a tracer. Availability of potassium has been shown to be correlated with the amounts of fine clay in the soil and with the levels of potassium in the fine clay.

The magnesium removed from soils by crops and grass was measured from experiments at Rothamsted and Woburn, and hay crops were analysed to show the effects of chalk and potassium fertilizer on the percentage of magnesium in the herbage. Crop samples from manurial experiments were analysed for copper, manganese, molybdenum and zinc to provide information on the uptake of these micro-nutrient elements and to see whether manuring affects the amount of them in the crop. The amounts of the so-called minor elements occurring in various soils are measured by spectrochemical methods, which are also useful in detecting injurious heavy metal contamination in sewage sludges.

In soil physics, research is going on to relate the movement of air and water in soils to the size and shape of the pores, laying a foundation for further studies of soil aeration and the supply of water to the growing plant. Other fundamental

studies include the physical chemistry of soil clays, important for the understanding of many soil properties that affect crop growth.

Work on soil fauna was extended during the year and several new investigations were started. These include studies of changes in the animal populations of soils being restored after open-cast coal-mining, and estimates of earthworm populations in orchards.

Botany and Biochemistry. As a contribution to understanding the effects of weather on crops, a long paper was published during the year describing fluctuations in temperature, humidity, and wind speed within and above a wheat crop in three successive summers. Recording of other factors in micro-climate includes measurements of radiation intensities within crops and of concentration gradients of carbon dioxide above crops. The information gained from work on evaporation and transpiration is being applied to a variety of problems in hydrology and irrigation at home and overseas.

When prolonged drought is broken by a little rain, sugar beet sometimes shows a spurt of growth and plants under these conditions may for a time grow faster than others which have been kept watered. This observation is being followed up by examining the effects of drought, and of irrigation, at different stages in the growth cycle.

Experiments have started to measure the losses of crop yield caused by different weed species and how they depend on the density of the weed population. Such information may make it possible to apply control measures more rationally, by deciding from knowledge of the nature and density of an infestation whether or not the increase of crop yield to be expected from eradicating the weeds would justify the cost.

Methods of extracting and preparing leaf protein for human consumption were further improved and extended to devising recipes for serving the material in palatable form.

Pests and diseases. The weather in 1959 favoured aphids, and yellows in sugar beet would have caused great losses had not insecticidal sprays been used on an unprecedented scale. Warnings of the need to spray were issued from Dunholme as the number of aphids reached the danger level in different districts, and more than 95 per cent of the total beet acreage was sprayed once, and much of it more than once. The results from widely-scattered experiments suggest that average yield was increased by 25 per cent as a result of spraying.

Work on aphid physiology, movement, and control continued. The factors operating in the mass migration of aphids were found to apply to migrant insects of other orders, and a general system of insect mass migration is being developed.

Further information was obtained about the distribution of both insect and fungus spores in the atmosphere. Many of the insects caught in nets at altitudes between 1,000 and 5,000 feet above the ground were alive and fertile, and produced live eggs or young when placed on suitable host plants. This confirms that many small day-flying insects can easily and safely circulate up to several thousand feet before being deposited, unharmed, on a plant. On several occasions traps operated in aircraft showed that the maximum concentrations of certain rust spores were at 3,000–5,000 feet, and meteorological findings indicate that these spores had come from Southern Europe.

The predators and parasites of wheat bulb fly were studied, and the Station's Annual Report contains an article reviewing current knowledge of the biology of this pest. The uptake, by wheat seedlings, of aldrin and dieldrin applied as seed dressings to kill wheat bulb fly larvae was measured by using materials labelled with radioactive chlorine as a tracer. This was part of a wider study of seed dressings and soil insecticides, including the use of systemic insecticides which may control pests on parts of the plant above ground as well as those attacking the underground parts.

Eelworms are particularly difficult pests to observe because of their microscopic size and the obscurity of the environments in which they are found. Special photographic techniques have been developed which make it possible to record their movement and feeding and films have been made to show their feeding mechanisms.

Among fungus diseases, long-term work continued on cereal foot rots, the relative susceptibility of different potato varieties to haulm infection by blight, and the soil conditions affecting severity of pea wilt. Among virus diseases of plants, attention was given to those affecting cereals, grasses and leguminous crops. The fungi occurring in mouldy hay was studied, partly as a cause of fodder spoilage but more because local contamination of the air by their abundant spores appears to be the cause of certain human and animal diseases.

Bees. Progress was made towards identifying "queen substance," and it is hoped that this may lead to its synthesis and tests of its application in practical beekeeping. Experiments to find the best time to take bees to a crop requiring pollination were extended: they show that delaying until the crops have begun to flower always increases the number of foragers and is particularly beneficial with a crop that has a short flowering period or is less attractive to bees than other flowers in the district. A special article in the Station's Annual Report summarises the information on infectious diseases of the honeybee.

Statistics. The electronic computer was very fully used during the year, and in addition to work for Rothamsted, much was done for other research organisations in this country and overseas.

A start was made on the construction of a "communication language" suitable for statistical programmes and the translation of programmes written for the Rothamsted 401 computer. This work is linked with similar work that is now proceeding in many quarters on the evolution of a universal programme language. The reason for it is that, as the use of computers increases, there is increasing need for some means by which programmes written for one type of computer can be translated for use on another type with less expenditure of time and labour than would be entailed in writing completely new programmes.

MACAULAY INSTITUTE FOR SOIL RESEARCH

Craigiebuckler, Aberdeen

Director: A. B. Stewart, M.A., B.Sc., PH.D., F.R.I.C., F.R.S.E.

Deputy Director: R. L. Mitchell, B.Sc., PH.D., F.R.I.C., F.R.S.E.

PEDOLOGY

Head of Department: R. C. Mackenzie,
D.Sc., PH.D., F.R.I.C.

W. A. Mitchell, B.Sc.

(Soil Mineralogy)

B. D. Mitchell, B.Sc., A.R.I.C.

(Physical Chemistry)

R. A. Robertson, B.Sc.

(Peat Ecology)

W. O. Binns, M.A., B.Sc.(FOR.), PH.D.

(Forest Soils)

H. G. M. Hardie, B.E.M., PH.D., A.R.I.C.

(Soil Analysis)

SPECTROCHEMISTRY

Head of Department: R. L. Mitchell, B.Sc.,
PH.D., F.R.I.C., F.R.S.E.

R. O. Scott, B.Sc., PH.D., A.R.T.C., A.R.I.C.

V. C. Farmer, B.Sc., PH.D.

A. M. Ure, B.Sc., PH.D.

BIOCHEMISTRY

Head of Department: J. S. D. Bacon,
M.A., PH.D.

R. B. Duff, B.Sc., PH.D.

R. I. Morrison, B.Sc., PH.D., F.R.I.C.

Secretary: Miss E. J. Dey

PLANT PHYSIOLOGY

Head of Department: P. C. DeKock,
M.Sc., D.PHIL.

W. M. Crooke, B.Sc., PH.D., A.R.I.C.

A. H. Knight, B.Sc., A.R.I.C.

(Radioactivity)

MICROBIOLOGY

Head of Department: D. M. Webley,
M.Sc., PH.D.

Miss M. E. K. Henderson, B.Sc., PH.D.

SOIL FERTILITY

Head of Department: E. G. Williams,
B.Sc., PH.D.

J. W. S. Reith, B.Sc.(AGR.), PH.D., A.R.I.C.

G. Anderson, B.Sc., PH.D.

STATISTICS

Officer-in-Charge: R. H. E. Inkson,
B.Sc., F.R.S.S.

Librarian: Miss A. M. B. Geddes, M.A., F.L.A.

The Institute takes its name from the late Dr. T. B. Macaulay of Montreal who founded it in 1930. Its primary aim is to obtain from field, pot, greenhouse and laboratory studies of soils and plants, information of value in the maintenance and improvement of soil fertility from the standpoint of both crop production and animal requirement.

On 31st March, 1960, the scientific and experimental staff numbered sixty-six.

CURRENT WORK

In the Department of Pedology the mineralogy of different soil types has been further studied by optical, X-ray, thermal and chemical methods in order to obtain a better understanding of soil-forming processes and the various factors operative in determining fertility. Particular attention is being paid to amorphous materials and mineral-organic complexes, which now appear to be more abundant than was previously realised, and the investigation of phosphate-mineral reactions is throwing some light on the fate of phosphate in soil. In addition to the study of ecological variations under artificially produced conditions, e.g. after heather burning on hill land and under different moisture regimes on deep peat, the surface water run-off from a peat catchment area is being characterised with a view to assessing the effects of agricultural practices. A technique involving radioactive phosphorus has given promising results in the examination of the rooting systems of plants growing on deep peat. The growth of trees and their fertilizer requirements on deep peat and other soils

has been further investigated and, arising from the observed occurrences of nitrogen deficiencies on shallow ploughed areas, particular attention is being paid to differences in the amount of mineralization of nitrogen as between deep and shallow ploughing on peat.

Study of the trace element contents of soils, plants and related materials has continued at an increased rate in the Department of Spectrochemistry in collaboration with other departments. The introduction of direct reading equipment and the application of new and more rapid techniques have facilitated the more intensive examination of problems related to such elements as magnesium, copper and manganese. Several instrumental modifications, designed to take advantage of the improved laboratory facilities shortly to become available, have been introduced. Work on the organic constituents of soils by absorption methods, again often in collaboration with other departments, has been extended and infra-red methods are proving useful also in the study of clay minerals.

Among interesting results obtained by the Departments of Microbiology, Plant Physiology and Biochemistry are further quantitative data on the solubilization of a variety of minerals, chiefly phosphates or silicates of calcium, magnesium and iron, by cultures of rhizosphere organisms, in which 2-ketogluconic acid is formed from glucose. Statistical analysis has shown that in iron-deficiency the level of malic acid in the leaves of mustard plants is depressed, while the citric acid is often higher; the preponderance of malic over citric acid in green leaves is reversed as the leaves become yellow. It has been found that the aconitase activity of the leaves, which is lower than normal in iron deficiency, is increased by toxic levels of nickel. The relation between cation exchange capacity and the pectin content of roots has now been shown to hold also for washed disks of storage tissues. The detection of lignin components in humic acids has been improved, and a sugar from the water-soluble polysaccharide fractions of soil and peat has been identified as 2-O-methyl-rhamnose. This sugar has previously been known only from glycolipids of certain *Mycobacteria*.

In the Department of Soil Fertility integrated field, pot and laboratory studies of the major soil groups, as mapped by the Soil Survey, and the main agricultural crops have been continued. Progress has been made in delineating the pivotal properties underlying the numerous and marked influences of parent material and drainage conditions on the inorganic phosphate relationships of soils, including effects on crops responses to broadcast and placed phosphate. Progress has also been made in studies on the organic phosphates in soils, including the development of improved methods of fractionation and estimation and an assessment of the phosphate and nitrogen present as deoxyribonucleic acid or related polynucleotides. Further useful information has also been obtained on the major and trace element status of different soil types, the nutrient requirements of different crops and on methods and times of applying fertilizers. Importance continues to be attached to the practical application of results through consultative activities, advisory soil testing and collaboration with kindred organizations.

In the design of experiments and the analysis of results the statistics section continues to give invaluable assistance both within the Institute and in outside collaborative work.

A more detailed account of the research in progress and particulars of published work will be found in the Institute's Annual Report.

SOIL SURVEY OF GREAT BRITAIN

England and Wales

Rothamsted Experimental Station, Harpenden, Herts.

Head of Survey: A. Muir, B.Sc., PH.D.

Deputy Head: D. A. Osmond, M.Sc., PH.D., A.R.I.C.

G. D. Ashley, B.Sc.
B. W. Avery, B.Sc.
C. B. Crampton, B.Sc., PH.D.
A. Crompton, B.Sc.
D. C. Findlay, B.A.
R. D. Green, M.Sc.
B. R. Hall, B.Sc.

C. A. H. Hodge, B.Sc.
R. A. Jarvis, B.Sc., F.R.G.S.
D. W. King, B.Sc., A.R.I.C.
H. H. le Riche, B.Sc., PH.D.
D. Mackney, B.Sc.
R. S. Seale, M.A.

Scotland

Macaulay Institute for Soil Research, Craigiebuckler, Aberdeen

Head of Survey : R. Glentworth, B.S.A., PH.D.

Deputy Head: J. W. Muir, B.Sc. (AGR.), A.R.I.C., N.D.A., N.D.D.

E. L. Birse, B.Sc.
R. Grant, M.A., B.Sc.
D. Laing, B.Sc., A.R.I.C.

J. M. Ragg, B.Sc.
J. C. C. Romans, B.Sc.
B. M. Shipley, B.Sc.

The Soil Survey is concerned with the systematic study and mapping of the soils of Great Britain. The total area mapped since 1946 is now more than 13,000 square miles. On the 31st March, 1960, the number of scientific and experimental staff was twenty-six in England and Wales and fourteen in Scotland.

CURRENT WORK

A total of 1,170 square miles has been mapped during the year in the counties of Bedford, Cambridge, Devon, Glamorgan, Hertford, Kent, Norfolk, Suffolk, Berkshire, Gloucester, Somerset, Sussex, York, Aberdeen, Ayr, E. Lothian, Perth, Ross and Stirling. Sheets 76 (Inverurie), 25 (Kelso), 26 (Berwick-on-Tweed) have been published; memoirs and maps for other areas are in the press. Special surveys again included areas of importance for town planning and experimental farms and the Survey is co-operating with the Advisory Service in a special study of the Lancashire mosslands. The Survey has produced a draft soil map of Great Britain on the scale of 1 : 1 million for inclusion in the Soil Map of Europe sponsored by the Food and Agriculture Organisation.

An annual report on the work of the Survey is issued by the Soil Survey Research Board.

A.R.C. UNIT OF SOIL PHYSICS

School of Agriculture, University of Cambridge

Director: E. C. Childs, SC.D., PH.D.

Senior Scientific Officer: E. G. Youngs, B.SC., PH.D.

The Unit studies those physical properties of soil which are markedly dependent upon the moisture content, and certain agricultural soil problems in which those properties play a dominant part. These problems lie chiefly in the fields of land drainage, irrigation and the role of the soil as the environment of plant roots.

During the year under report, the chief progress to be recorded has been (a) the study of the collapse of an initially saturated moisture profile above a water-table; (b) the establishment of principles of design of three dimensional drainage systems; and (c) the test in the field of the principles of design of two-dimensional drainage systems established in the laboratory.

It is surprisingly often found that the phenomena of water movement in porous materials are closely akin to these in highly-simplified and idealised systems. A study of the descent of water meniscuses in capillary tubes which dip under free water surfaces has led to the derivation of mathematical expressions describing the dependence of the rate of issue of water on the passage of time, and observation of the rate of delivery of water from an initially saturated column of porous material to a water-table has shown quite close agreement with the theoretically-derived equation. A flux component of this kind is of significance in the problem of the location of a momentary stage in the descent of a non-steady water-table following cessation of rainfall.

Three dimensional drainage systems are those in which it may not be assumed that the drain lines are very long compared with their separations. Both theoretical and experimental studies have been successfully made of the control of a water-table by means of mesh systems of drain lines with various ratios of separation of major and minor drains. Drainage by pumping from arrays of wells, as practised in parts of Pakistan and India, has also received attention.

In the field, the work reported last year to test the predicted behaviour of drains, has been carried a stage further, good agreement with theory based on measured soil permeability having been obtained up to a point. Departure from agreement coincided with the water-table reaching the level of an old system of drains whose presence had gone undetected in the preliminary reconnaissance but had been revealed during the laying of a new system. The avoidance of this uncertainty is now the only outstanding problem.

An interesting new permeameter for laboratory use has been designed and satisfactorily tested. Its functioning is based on the imposition of an oscillating pressure head.

PLANT BREEDING

PLANT BREEDING INSTITUTE

Maris Lane, Trumpington, Cambridge

Director: G. D. H. Bell, B.Sc., PH.D.

CEREALS (WHEAT, BARLEY, OATS)

G. D. H. Bell, B.Sc., PH.D.

F. G. H. Lupton, M.A.

R. N. H. Whitehouse, M.A.

LÉGUMINOUS FORAGE CROPS AND GRASSES

J. L. Fyfe, M.Sc.

H. H. Rogers, B.Sc., DIP.AG.SCI.

PATHOLOGY

R. C. F. Macer, M.A., PH.D.

MUTATIONS

A. D. McKelvie, B.Sc., DIP.AG.SCI., D.T.A.

BIOCHEMISTRY

A. R. H. Trim, B.A., PH.D.

POTATOES AND BRASSICAS

H. W. Howard, B.A., PH.D.

K. F. Thompson, M.A.

SUGAR BEET

G. K. G. Campbell, B.Sc., A.I.C.T.A.

G. E. Russell, M.A., DIP.AG.SCI.

CYTOGENETICS

R. Riley, B.Sc., PH.D.

Secretary: F. B. Hatfield, B.Sc., D.P.A.

The work of the Institute is concerned primarily with the improvement of the important crop plants that are an essential and integral part of the rotational systems in the intensively-farmed arable areas of England, including those systems which involve the use of rotational grass. The agricultural area to which the work is particularly applicable includes those parts of the country devoted to the production of cereals (primarily wheat and barley), potatoes and sugar beet, and these crops occupy a large part of the Institute's work. In addition the following crops are being studied intensively—oats, marrowstem kale, field beans, lucerne and two rotational grasses (cocksfoot and tall fescue). A small amount of work is being conducted on red clover and thousand head kale.

The investigations include the improvement of such characters as yield, quality, disease and pest resistance, winter hardiness, drought resistance and those special characters associated with ecological adaptation for special purposes such as earliness or, as in the case of grasses, the capacity to make out-of-season growth. Research is therefore being conducted on particular fundamental problems in physiology, biochemistry and chemistry, mycology and virology, while researches of special application to cereal breeding are being conducted in cytogenetics and pathology. An integral part of the work in all crops is the study of breeding methods, including the application of statistical and biometrical techniques. A fuller account of the Institute's work is given in its Annual Report for 1959-60.

On the 31st March, 1960, the scientific and experimental staff of the Institute numbered twenty-six.

CURRENT WORK

The improvement of yield and grain quality is the main objective in all the cereal investigations, and all aspects of the various characters which determine limit and yield are under study. New hybrids of winter wheat have been produced which show an advance in the combination of yield with good milling and baking quality, while particular attention is being paid to the maintenance, and improvement, of the level of resistance to the diseases yellow rust, powdery mildew, loose smut and eyespot. Apart from exploiting by hybridisation the disease resistance of named varieties, new parental types specially synthesised by interspecific hybridisation are being used to ensure the incorporation of as many sources of disease resistance as is practicable. This has involved an intensive study of the genetics of resistance in certain of the diseases, and the exploitation of field and glasshouse testing of hybrids developed by rapid backcrossing techniques under glasshouse conditions. Similar work with powdery mildew resistance is being undertaken in barley and oats, and in the former new resistant spring hybrids are in the final stages of trials. A new winter oat variety bred at the Institute has been marketed, and another is being multiplied for marketing when there is sufficient seed.

The genetic and physiological basis of yield in all the cereals is being studied in several ways, including a detailed investigation of the behaviour of yield components in diallel sets of crosses, with also a biometric analysis of individual cross performance for the isolation of the most promising parental combinations in breeding for high yield. This work is providing information on the most efficient way of planning hybridisation programmes with particular reference to breeding for increased yield, which is of the first importance in each of the cereals, but has especial significance in the breeding of feeding barleys.

The pathological research on fungal diseases of cereals has developed towards more fundamental studies on the pathogens and on the genetic basis of host-parasite relationships. Collaborative work on certain diseases has been established on an international scale, and collections of cereal pathogens have been maintained. Surveys of the incidence of individual pathogens, and of their component races where these are relevant, have been undertaken in co-operation with other workers, and further progress has been made in the improvement of disease-testing techniques.

Further information of importance has resulted from the cytogenetic research on wheat and its near relatives. This information is not only fundamental to a proper understanding of cytogenetic phenomena in polyploid wheat species, but also introduces new ideas concerning practical possibilities in wheat breeding. The most significant finding has been the association of the control of meiotic chromosome pairing with genes on one particular wheat chromosome, and this knowledge may be exploited to overcome the difficulties so far experienced in the transfer of valuable characters from related species to bread wheat. On the other hand, progress has been made in transferring individual rye chromosomes to wheat by addition or substitution, while chromosome deficient lines in certain wheat varieties are being developed for use in breeding and genetic work.

The use of selected techniques for the artificial induction of mutations has been studied in various ways and, in particular, work has proceeded on the use

of irradiation and various chemicals for increasing the rate of mutation, and for influencing the kind of mutation, in barley and in a quick growing annual plant of no commercial importance. Irradiation techniques have also been used in genetic studies in potatoes, on wheat intervarietal hybrids and in intergeneric hybrids involving wheat, while mutant forms produced by irradiation in barley have been incorporated in the breeding programme.

New selections of sugar beet have now been produced which should make it possible to improve the field performance of the bolting-resistant variety which has been made available to growers, and these selections are being multiplied with a view to their substituting the original stock. There has been further marked progress in the isolation of selected lines of sugar beet showing tolerance to the yellowing viruses, and the initial stages of the synthesis of new tolerant stocks have been carried through after conducting small-scale field trials. It has been found necessary, however, to continue the fundamental researches on the strain relationships in this virus complex using single-aphid transmissions, and this work has proceeded in conjunction with the virus strain survey in the sugar beet growing areas. These studies have made it necessary to include the mild yellowing virus in addition to the strain complex already being used in the work on selection of tolerant lines. Work has continued on the electron microscopic study of the virus particles, combined with improved methods of isolation from the infected plants, which have made it possible to obtain further knowledge on the structure of the virus.

Potato clones carrying two major genes for resistance to late blight have been included in national trials and investigations started on devising adequate tests for field resistance and tuber resistance to this disease. Considerable progress was made in the breeding of potatoes showing resistance to the common type of root eelworm, and one further clone was sent for registration trials. Studies on the effect of growing eelworm-resistant potatoes in infected soils have shown that the fall in the eelworm population was much greater than from fallowing. In the meantime, breeding material has been developed by interspecific hybridisation for the exploitation of the resistance to the so-called resistance-breaking biotype of the eelworm. The general breeding programme has made progress in the development of clones to replace the long-established varieties Majestic and King Edward.

Sufficient progress has been made with the breeding of marrowstem kale for a stock to have been built up of a double-cross hybrid for entry in national trials. This hybrid is a short-stem type suitable for strip grazing, and it has been selected for stems of greater edibility and with more leaf, a better leaf retention and greater winter-hardiness. Work has continued on the further improvement of this type of kale, and also of medium height and tall types.

Efforts to improve the stocks of field beans available to farmers have continued to concentrate on producing hybrid varieties of winter beans through the exploitation of male-sterility. Further experiments have been conducted on the feasibility of producing hybrid seed on a commercial scale, and small-scale experiments have again demonstrated the higher yielding capacity of such hybrids.

A start has been made to combine in lucerne resistance to *Verticillium* wilt and to stem eelworm, while the level of resistance of red clover breeding material to stem eelworm has been improved. The breeding and genetic investigations

in lucerne have continued, as have the investigations on breeding techniques in grasses. Interesting results have been obtained from a study of tall fescue grasses from North Africa, as these grasses show an exceptional capacity for winter growth.

WELSH PLANT BREEDING STATION

Plas Gogerddan, Aberystwyth

Director: Professor P. T. Thomas, B.Sc., PH.D.

Deputy Director: Gwilym Evans, O.B.E., M.Sc.

DEVELOPMENTAL GENETICS

J. P. Cooper, B.Sc., PH.D. (Genetics)

P. B. Vose, B.Sc., N.D.A. (Physiology)

GRASS BREEDING

A. R. Beddows, M.Sc., F.L.S.

Martin Borrill, B.Sc., PH.D.

E. L. Breese, B.Sc., PH.D.

Ieuan Davies, M.Sc.

CLOVER BREEDING

W. Ellis Davies, B.Sc.

Alice M. Evans, B.Sc., PH.D.

CEREAL, BEANS AND BRASSICAE BREEDING

D. J. Griffiths, M.Sc., PH.D.

GRASSLAND AGRONOMY

Ll. Iorwerth Jones, B.Sc.

D. G. Miles, B.Sc.

Arthur Troughton, M.Sc., PH.D.

A. H. Charles, B.Sc.

SEED MULTIPLICATION

Gwilym Evans, O.B.E., M.Sc.

H. M. Roberts, B.Sc.

Joseph Lewis, B.Sc.

CYTOLOGY

Keith Jones, B.Sc., PH.D.

PLANT PATHOLOGY

A. J. H. Carr, B.Sc., PH.D.

CHEMISTRY

G. ap Griffith, M.Sc., PH.D.

SCIENTIFIC LIAISON OFFICER

Ll. Phillips, B.Sc.

Secretary: J. W. Ellis, D.P.A., A.C.I.S.

The Station is concerned with fundamental and applied research associated with the production of improved varieties of grasses, legumes, cereals, beans and forage *Brassicæ* crops. Particular attention is given to the production of adapted varieties for both lowland and upland conditions.

On the 31st March, 1960, the scientific and experimental staff of the Station numbered forty.

CURRENT WORK

Developmental Genetics. (i) *Genetics.* The heritability of leaf size and rate of leaf appearance has been estimated from parent/progeny correlation and from the analysis of full sib families. Some additive genetic variation for both characters exists within varieties and rapid response to selection occurs.

In the selection experiment for date of ear emergence in Irish and Kent ryegrass the response continued in the fifth year, but low fertility has appeared as a correlated response.

The genetic control of dry matter production under controlled competition and defoliation has been studied, using a simulated sward technique.

(ii) *Physiology*. The physiology of the vegetative grass plant has been studied and basic information obtained on growth pattern.

The aim of the work on intraspecific differences in nutrient uptake and assimilation is to uncover as much as possible of the potential nutritional variability in *Lolium* and *Trifolium* spp. and to select plants which may be better adapted to growing under hill conditions on soils of low pH and of low calcium status. Techniques capable of dealing with large numbers of plants are being devised to measure very small variations in nutrient uptake.

Grass Breeding. The desirable agronomic characters in grasses exhibit continuous variation, their genetic control is complex and their expression is markedly influenced by environmental conditions. The technique of breeding is therefore determined by the necessity to distinguish between genetic and environmental effects in the plant material by means of a suitable procedure for progeny testing. Investigations involving the use of the diallel cross have shown in ryegrass that relatively small numbers of mother plants can be used in the synthesis of a new variety. They have also indicated the possible limits beyond which it may be necessary to employ more elaborate techniques of varietal construction in order to maintain vigour during seed multiplication.

Herbage Legume Breeding. Studies of white clover populations from Europe have shown a continuous cline of variation from the large-leaved, tall-growing cyanogenetic plants of the Mediterranean region, to the small-leaved, low-growing acyanogenetic types from Norway and other high latitude and high altitude areas. Attempts to combine the large leaf of the Ladino type of clover with the persistency of Aberystwyth S.100 show considerable promise.

Although 1959 was an excellent year for clover seed production, the seed-set of polyploid clovers was rather poor. Studies on this problem in red clover indicated that the longer corolla tubes of the polyploids, and irregularities between fertilization and maturation of the embryo, were the major factors involved.

Work was commenced on legume/rhizobium relationships with a view to improving the level of symbiosis in white clover. A wide range of genetic variation has been found both in host reaction and in the bacterial strain.

Cereals, Beans and Brassicae Breeding. Work on the production of new disease-resistant varieties of spring and winter oats has produced encouraging results. Two new varieties of oats have been released to the Trade, S.227 Pennant winter oats, a stem-eelworm resistant variety, and S.235 Manod, a spring oat which exhibits a high degree of resistance to stem eelworm, mildew and crown rust.

The spring barley breeding programme has been expanded. The most striking development in the barley work was the discovery of the differential response of some commercial varieties to DDT spray; the reaction is controlled by a single gene with susceptibility to damage being dominant to resistance. This has provided a convenient means whereby the purity of varietal stocks can be quickly assessed, and the technique has already proved of value.

Progress has been made in the breeding and selection of *Brassicae* crops for upland and lowland conditions. A clubroot-resistant variety of rape is

in process of development and progenies from a wide range of crossing combinations of *Brassica oleracea* are being tested under different environmental conditions.

Grassland Agronomy. The assessment of grass varieties in swards shows that the results obtained under one system of management may differ markedly from those under other systems. For example, the ryegrasses respond less favourably to inorganic fertilizers and to mowing than the cocksfoots. Less striking differences can also be detected between varieties of the same species. Thus the value of a particular variety to the farmer can only be properly assessed by fairly elaborate techniques which take into account the demands to be made on it in actual farming practice. Investigations on new varieties which have not yet been released to the trade are, therefore, designed to establish not only their particular characteristics but also the conditions required for their full exploitation by the farmer.

The greatest need in hill pasture improvement in Wales is the introduction of a vigorous legume, together with grasses which establish well and persist under relatively adverse conditions. Grazing trials with sheep at an altitude of 1,250 feet have demonstrated the value of swards produced from improved varieties of grass and clover, not only two or three years after sowing, but up to 14 years. These improved swards, compared with the native pasture, carried twice as many breeding ewes and produced $2\frac{1}{2}$ times as many lambs. The lambs were heavier and in better condition, and valued at a higher price. The money returns per acre in terms of lambs produced were three times as high compared with those on the native pasture.

In order to study the establishment, persistency and productivity of different species and varieties for further breeding, a number of small hill areas near Aberystwyth are being subjected to different cultural treatments, some of which also involve the use of chemical herbicides. These areas have been chosen to represent different hill associations where the dominant plants are *Agrostis*, *Agrostis/fescue*, *Nardus/fescue*, heather or *Scirpus*.

Seed Production. Maximum seed yields have been obtained and heavy losses in yield avoided in several varieties of grasses by harvesting the crops when traces of green still remain in the heads and the endosperm is in a cheesy condition.

In the studies on the effects of seed rates on seed yields it has been found that some species of grasses are much more sensitive to density than others, and that effects last longer in some species. Most of the varieties investigated produce better seed yields from much lower sowings than the standard rates.

The physiology of growth habit and flowering in herbage legumes is under study. Initial work has been concerned with factors influencing stem and internode development, and seedling characters of importance in varietal identification.

Work with mature plants of *Trifolium pratense* has indicated that spraying with gibberellic acid induced earlier flowering and also increased the number of heads per plant. To obtain these responses it is necessary to spray during the extension of the first three stem internodes. Seedlings of S.123 red clover sprayed at stages up to the seventh trifoliate leaf developed into single stem types, but successive sprayings encouraged branching.

Studies on the influence of water table, soil depth and soil type on the survival of certain crop and weed seeds have shown that the rapid depletion of seed numbers in loam soil, sand and peat up to a maximum depth of eight inches was found to be mainly attributable to germination *in situ*. Seeds below the water table remained dormant and highly viable after two months, whereas those above the water table had germinated freely and consequently soon perished.

The effect of a cereal cover crop on the seed yield of grasses has shown that better yields are obtained in the absence of a cereal cover crop, but when it is absolutely essential to grow a cereal its depressing effect can be partly limited by blocking one spout in three or four of the cereal drill.

Plant Pathology. Investigations were made into the incidence and effect of phyllody and other virus diseases of white clover. Two surveys were undertaken in 1959; the data from these have been collated and two reports prepared for limited circulation. Results indicate that phyllody-infected plants have abnormal hormone levels.

Work on fungus diseases included *Verticillium* wilt on lucerne, clover rot, and also black stem disease of lucerne.

Cytology. The results of the statistical analyses of a randomised block lay-out to compare the morphology of 4x, 5x and 6x *Holcus mollis* confirm that none of the numerous characters measured can be used to separate the chromosome races in the field. Similar analyses on *H. lanatus* ($2n = 14$), *H. mollis* ($2n = 28$) and different F_1 hybrids between them show the hybrids to be very similar to *H. mollis* in floral characters.

The Cytological Survey of extensive collections of *Dactylis* spp. supplied by F.A.O. has been completed. A list of chromosome numbers is available to research workers interested in this material.

Chemistry. Studies on the nitrate nitrogen content of herbage have been continued and expanded to include oats, kale and rape. Samples of rape showed some of the highest contents yet found. The results show that nitrate accumulation is an abnormality which does not of necessity appear only with excessive nitrogen applied unseasonably with too short an interval after manuring to allow the plants to dispose of it. Nitrogen used in the ammoniacal form does not prevent the accumulation.

A fuller description of the Station's work is given in its Annual Report for 1959.

SCOTTISH PLANT BREEDING STATION

Pentlandfield, Roslin, Midlothian

Director: J. W. Gregor, D.SC., PH.D., F.R.S.E.

POTATO BREEDING

W. Black, D.SC., PH.D., F.R.S.E.

VIRUS DISEASES OF POTATO

G. Cockerham, B.SC., PH.D.

OATS

D. Cameron, B.SC.

HERBAGE PLANTS AND GENECOLOGY

Patricia J. Watson, M.A., PH.D.

D. J. Harberd, M.SC.

BRASSICAE BREEDING

V. E. M. Davey, B.SC., PH.D.

BRASSICA CYTOGENETICS

I. H. McNaughton, B.A., D.PHIL.

Secretary: R. J. L. Gallie

The aims of the Station, established by the Scottish Society for Research in Plant Breeding in 1920, are: (a) to conduct investigations calculated to yield information of scientific interest bearing upon the general problems of crop improvement; and (b) to produce new and improved varieties of direct value to agriculture.

On the 31st March, 1960, the scientific and experimental staff numbered sixteen. The work of the Station as a whole is largely directed towards reducing crop losses due to disease. In fact the study of resistance to disease, involving the nature of resistances and their modes of inheritance, enters to a greater or less extent into the programmes of all Sections. For instance, resistance to blight, common scab, virus diseases and root eelworm in potatoes, stem eelworm in oats, club-root in *Brassica* all come within the scope of the overall programme, as well as a preliminary examination of the incidence of virus diseases in grasses.

There are, however, other subjects under study including a genecological study of species that contribute to the plant communities of upland grazings, and this has been chosen for special mention in this year's report. The genecological techniques employed are in some respects novel. Instead of following the customary genecological practice of taking large samples of a single species from a few habitats, small samples of several taxa (*Agrostis* spp., diploid and tetraploid *Festuca ovina*, *Potentilla erecta* and *Plantago lanceolata*) were collected from a large number of spatially separated sites scattered throughout a mosaic of five relatively well-defined types of habitat.

A feature of the analyses of the data amassed during the course of this study is that, instead of using the usual within-population variance as the error item, it has been possible to employ the variance between populations from ecologically similar sites. The analysis adopted for each character scored was the simple analysis of variance between groups, using the site-population means as the primary data. This type of trial is attractive because the same series of site means can be classified in several different ways, each one leading to its own analysis. Thus, by grouping the sites phytosocially, or by altitude, geography, etc., an estimate can be obtained of the importance of the particular factor in population differentiation.

The stems, or leaves produced in the "wild" were measured when the samples were collected. The analyses show that within a species there is a significant tendency for the "wild" measurements to be correlated with measurements obtained from the same samples in cultivation, though it apparently requires considerable differences in habitat conditions before exogenous adaptation becomes associated with detectable ecotypic differentiation.

In the garden-grown material it is found that sites with, for example, genetically tall plants of one species tend to have genetically tall plants of the other species. Such significant correlations can be obtained without imposing any kind of classification on the sites, but it is noteworthy that the correlations within any one of the classified types of habitat are very considerably reduced, indicating that the habitat classification adopted was efficient at breaking up the range of important environmental factors into reasonably homogeneous units.

A more detailed account of the Station's work is given in its Report for 1960.

A.R.C. UNIT OF BIOMETRICAL GENETICS

Department of Genetics, University of Birmingham, Edgbaston, Birmingham

Honorary Director: Professor K. Mather, C.B.E., D.SC., PH.D., F.R.S.
(Professor of Genetics, University of Birmingham)

Honorary and Senior Scientific Staff:

B. John, M.SC., PH.D. (*Honorary Member*)
J. L. Jinks, B.SC., PH.D.
R. Morley Jones, B.SC.

The Unit was formed on 1st October, 1950. It is attached to the Department of Genetics in the University of Birmingham and the Professor of Genetics is its Honorary Director. On 31st March, 1960, the scientific and experimental staff numbered six.

CURRENT WORK

The principle of nuclear cytoplasmic interaction is implicit in the cell theory and, while most biologists would accept it, little is known of the precise role of the cytoplasm in this process. Fungi offer special advantages for its study and investigations on the fungus *Aspergillus* have over the last few years displayed the interaction of nucleus and cytoplasm in a number of ways. One of the more remarkable examples concerned a cytoplasmic particle which had been induced to mutate by ultra-violet irradiation. This mutant particle maintains itself indefinitely, provided it is associated with a wild-type nucleus. A single gene mutation in this selfsame nucleus, however, leads to progressive and rapid diminution in the numbers of the mutant particle in the cytoplasm: indeed, eventually it is always completely lost despite heavy selection applied to maintain it. Clearly in this case cytoplasmic regulation is under the genetic control of the nucleus. Not all changes in the frequency of mutant cytoplasmic particles, however, can be related to nuclear gene changes. They may occur

during the normal development and differentiation of a colony whose complement of nuclear genes is not changing. A cytoplasmic mutant induced by treatment with acriflavine affords an example. This particle may be present in a high proportion of the growing points of a colony. It is then present in some of the asexual spores but never in the sexual spores although these are produced by the self same colony. This suggests a relationship between the local frequency of the mutant particle and the type of differentiation pattern which the colony develops.

The implications of these results are not confined to experimental fungi raised in the laboratory. Certain wild fungi commonly exist in two alternative forms—the so called “dual phenomenon”—and this behaviour is at least in part cytoplasmic in origin. Again the adaptation of the potato blight fungus, *Phytophthora infestans*, to rapid spread in tubers of a particular variety of potato probably depends on a natural adjustment of the cytoplasm.

It is now well established in plants that any change in the natural breeding system of a species results in an upset of chromosome behaviour. Thus the enforcement of inbreeding in a naturally cross-pollinating plant such as rye brings about a variety of abnormalities in the chromosomes of the inbred individuals. This relationship can now be extended to animals, for inbreeding in the locust *Pyrgomorpha kraussi* results in a syndrome of effects which involve abnormality of both the number and structure of the chromosomes. Normally chromosome behaviour is self-regulating in that abnormality leads to reduction of fertility and hence the selective elimination of the unbalanced genotypes which bring about the abnormality. This selective regulation is not, however, always effective. Some wild populations of grasshoppers show extensive abnormalities of chromosome structure even under the natural breeding system and the consequent reduction in fertility does not appear to bring about their elimination. Chromosome abnormalities are now known to occur regularly in man as in populations of other animals and two new instances have been added to the list by the department during the past year.

Continuing our new approach to the estimation of the number of effective genetic factors controlling continuously varying characters the theoretical consequences of linkage between dominant genes on this estimate have been investigated. Preliminary applications to experimental data have been encouraging, but have served mainly to re-emphasise the importance both of any special relations between genotype and environment and of the influence of the management of young seedlings on the adult performance. A new experimental study of the basis of our methods of biometrical genetics has begun in the fruit fly *Drosophila melanogaster*, in which genetic differences of known effect can be put together and the outcome of the analysis thus compared with the known properties of the system of variation. Early results suggest that this approach may be of considerable value in leading to a clearer understanding of the technique of assessment by diallel crosses which is now gaining a place for itself in plant breeding practice.

PLANT PHYSIOLOGY

A.R.C. UNIT OF PLANT PHYSIOLOGY

Imperial College of Science and Technology, London, S.W.7

Director: Professor H. K. Porter, D.SC., A.R.I.C., D.I.C., F.R.S.

Senior Scientific Staff:

Miss O. N. Purvis, D.SC., PH.D.

C. L. Mer, B.SC., PH.D., A.R.C.S.

The Unit was formed on 1st January, 1959, and is attached to the Department of Plant Physiology at the Imperial College. On 31st March, 1960, the scientific and experimental staff numbered eight. This report is especially concerned with one aspect of the recent work of the Unit, namely the effect of high temperatures on the vernalisation of cereals.

Vernalisation (exposure of germinating seeds or green plants to low temperature between 0° C. and 7° C.), is well known to affect the flowering behaviour of plants. For example, the time taken by spring-sown winter cereals to reach the stage of ear formation may be reduced from six months to six weeks by vernalisation, and the flowering of rye is hastened by exposing the plants to low temperature at any time between germination and the beginning of ear development.

Exposure to high temperature (20° C. or over) may modify or even annul the effects upon flowering of exposure to low temperature. This was first apparent in some experiments in which germinating seeds were exposed alternately to single days at low temperature and single days at high temperature (20° C.). Under these conditions there was no acceleration of flowering, although the total time at low temperatures was adequate. In addition, single days at high temperature were inserted between low temperature periods of increasing length, (2, 3, 6 days) so that the time of exposure to low temperature was kept constant at 42 days. Increasing the length of the periods at low temperature progressively reduced the time to flowering by amounts proportional to the fraction of the total time occupied by high temperature treatment. These observations led to an extended study of high temperature effects in relation to vernalisation, the results of which are summarised here.

In the early stages of investigation into vernalisation, it was suggested that as the length of the period at low temperature is increased an initially unstable intermediate produced from a precursor became stabilised. A similar stabilisation effect was evident as the high temperature periods described above were given at longer and longer intervals. It became clear that there must be a transition from a condition under which vernalisation is promoted to one in which it is prevented as the environmental temperature rises. This transition temperature, at which neither vernalisation nor devernalisation occur, was found to be about 15° C. If germinating seeds or plants are held at 15° C. for 2-4 days after vernalisation, the subsequent devernalisation effect

of high temperatures is annulled. The stabilising process, which makes vernalisation irreversible by heat, therefore proceeds at all temperatures up to 15° C., i.e. at a higher temperature than that which will promote production of the proposed unstable intermediate. At 20° C., devernalisation by heat is not very marked, but the effect increases with rising temperatures up to 40° C. Observations above this temperature are not possible because the plants will not survive. It is, however, noteworthy that high temperatures never effect complete devernalisation. By varying the time of exposure to heat, after six weeks of vernalisation, from 0-5 days, it was found that the partial annulment of vernalisation was proportional to the time of exposure to high temperature. When both duration of vernalisation and the time of subsequent exposure to heat were varied a very complex system of interrelations was revealed. At 20° C. the amount of devernalisation reached a maximum after about 12 days and further exposure to this temperature accelerated flowering. Indeed after 28 days of heat treatment the time to flowering was actually shorter than for plants vernalised for six weeks. It was the same as that in plants which had been vernalised for nine weeks and received no heat treatment.

A similar situation obtains in plants exposed to 25° C., but the response to treatment is not so uniform, and prolonged exposure does not add to the effect of six weeks vernalisation. On the whole, the evidence supports the conclusion that the time to flowering, optimal after about 12 days, is again shortened with increasing heat treatment. These effects of heat given after vernalisation can be satisfactorily explained in terms of a reversal of changes initiated by exposure to low temperature, but it has now been discovered that high temperatures, given prior to vernalisation, also partially annul the low temperature effects. This latter finding of course cannot be explained in the same way since the labile intermediate substance must be supposed to be absent in unvernalsed grain. The heat effects have been found to be remarkably similar both on whole grain during germination and on growing plants, whether the treatment is given before or after vernalisation. An interesting feature of these later experiments was the observation that excised embryos, cultured on sucrose, seem to be less susceptible in respect of devernalisation to the heat treatment applied before vernalisation than is whole grain, although the response to post-vernalisation high temperature is the same in both. Such a difference might possibly be explained by some effect on the movement of material from the endosperm not operative in excised embryos supplied with unlimited substrate, but it is perhaps difficult to reconcile the similar response of growing plants with such a hypothesis.

Other research in progress concerns the soluble nucleotides of germinating wheat, products of sulphate reduction in plants and carbohydrate metabolism in leaves. An investigation of the possible effect of manganese on the sensitivity of oat seedlings to light has been completed. The addition of manganese effects neither the light sensitivity nor the growth of oat seedlings.

A.R.C. UNIT OF PLANT MORPHOGENESIS AND NUTRITION

Wye College (University of London), Ashford, Kent

Director: F. J. Richards, D.SC., F.R.S.

Principal Scientific Officer: W. W. Schwabe, D.SC., PH.D., A.R.C.S.

The Unit was established in January, 1959, and is concerned with (a) morphogenetic aspects of plant development, especially photoperiodic behaviour, flower induction, and apical correlations, and (b) physiological effects of deficiencies of the major nutrient elements. On 31st March, 1960, the scientific and experimental staff of the Unit numbered two.

Earlier studies of the "critical daylength" in long-day plants were extended in investigations in which several species of *Epilobium* were used. As regards induction of flowering, a complex relationship was shown to exist between the length of the daily period of exposure to light and the number of inductive cycles given. Also, detrimental effects on the flowering of these species were revealed when even very short daily dark periods were allowed to interrupt a regime of otherwise continuous light. Experiments with synthetic plant hormones in different daylengths showed that treatment with gibberellic acid notably promotes flowering in "near-critical" photoperiods, but that in short-day conditions its effects are confined to stem growth. It was also found that flowering and internode elongation, normally closely associated, can in fact be affected independently, so that in certain conditions quite tall plants remain vegetative. Moreover, changes in phyllotaxis which normally occur only at the onset of flowering may be induced in strictly vegetative plants by appropriate daylength treatment.

The general study of the effects of daylength and other environmental factors on growth and reproduction of *Lunularia cruciata* has been concluded, only one aspect of this work being continued, namely, the effect of light from restricted spectral regions on the daylength responses of the liverwort. The necessary apparatus has been constructed and is now being used. In addition, investigations have been begun into changes in the "apparent viscosity" of the cytoplasm of a short-day—requiring plant when exposed to different photoperiodic treatments. A technique has been developed, and the first experimental results indicate that such treatments do indeed affect considerably the ease of centrifugation of intracellular particles.

If Chrysanthemum cuttings are treated with tri-iodobenzoic acid their phyllotaxis alters from the normal spiral to the alternate arrangement, which persists for some time. Sections show this change to be associated with enhanced and premature internode elongation, which is evident even in the region of the very youngest primordia.

Studies involving feeding plants with arginine containing C^{14} have emphasised the probability that this amino-acid is a precursor of the putrescine which may accumulate naturally under conditions of potassium deficiency. Detailed chromatographic analysis of leaf material from normal and potassium-deficient barley have confirmed the earlier preliminary result that no large qualitative or quantitative differences exist between these plant types as regards

their free nucleotide composition. The experiments therefore lend no support to the view that in potassium deficiency the uncoupling of phosphorylation from oxidation is an important factor underlying the general symptoms of deficiency, and especially the characteristically high respiration rate.

PLANT GROWTH SUBSTANCES

A.R.C. UNIT OF PLANT GROWTH SUBSTANCES AND SYSTEMIC FUNGICIDES

Wye College (University of London), Ashford, Kent

Honorary Director: Professor R. L. Wain, D.Sc., Ph.D., F.R.I.C., F.R.S.
(Professor of Agricultural Chemistry and Head
of Department of Physical Sciences)

Senior Scientific Staff:

C. H. Fawcett, M.Sc., Ph.D., A.R.I.C.
D. M. Spencer, B.Sc., Ph.D.

H. F. Taylor, B.Sc.(Hort.)
S. T. C. Wright, B.Sc., Ph.D.

Two main fields of research are covered by the Unit. Firstly, physiological studies on chemicals which control and modify plant growth and, secondly, investigations on fungicides and fungicidal action. Both involve basic research in which chemists and biologists work in close co-operation and a number of the projects under investigation are of a long-term nature. It is nevertheless hoped that some of the results will lead eventually to better methods of crop production, for example, by achieving improved plant growth or by weed elimination or by discovering more effective means of controlling plant diseases. Some successes in these directions have already been achieved.

On the 31st March, 1960, the scientific and experimental staff of the Unit numbered eight.

CURRENT WORK

The long-term investigations on the relationships between chemical structure and plant growth-regulating activity have led to the discovery of new active compounds which may find specific uses in agriculture. Much work is being carried out on the metabolism of growth substances and other compounds within plant tissues. This forms part of a wider study of selective toxicity which is being developed logically from the results of previous investigations carried out within the Unit.

In collaboration with Professor T. A. Bennet-Clark, of King's College, London, attempts are being made to isolate and identify a potent abscission accelerator and hormone inhibitor which is present in the seed pods of yellow lupin and the crop is being grown on a field scale in order to provide adequate supplies of the material for study. Little is so far known of the chemical nature of naturally occurring hormone inhibitors and this new substance might be of significance in helping to understand the nature of plant growth.

New chemicals are being synthesised for studies on fungicidal action and the possible chemical nature of disease resistance in plants is receiving some attention.

Three widely different types of chemical substance are now believed to play specific roles in the growth of plants. These groups have been classified as gibberellins, kinins and auxins. Work of fundamental physiological importance is proceeding to determine whether these substances act individually or collectively in the growth of plant tissues. To date, experiments with wheat coleoptiles have shown that very young plant cells are particularly sensitive to a gibberellin (gibberellic acid), whereas the cell does not respond, by increased growth, to auxin (indolyl-3-acetic acid) until it is relatively much older. The special role played by kinins (kinetin) appears to be in cell division. As a result of these experiments it has been established that plant cells exhibit a sequential growth response, first to a gibberellin, then to a kinin and finally to an auxin. The possibility is now being investigated that each growth stage of the cell might require a particular concentration ratio of these three types of substance and that growth and differentiation can only proceed when certain concentration ratios are presented to the cell in a particular predetermined (genetic) order.

PASTURE

GRASSLAND RESEARCH INSTITUTE

Hurley, Maidenhead, Berkshire

Director: William Davies, D.SC.(WALES), HON.D.SC.(N.Z.)

Deputy Director: T. E. Williams, B.SC.

LEY AGRONOMY

Head of Department: T. E. Williams, B.SC.

C. R. Clement, B.SC., PH.D.

A. J. Heard, M.SC.

W. Stiles, M.SC.

MICROBIOLOGY

Miss E. Grossbard, PH.D., D.I.C.

HERBAGE AGRONOMY

Head of Department: J. O. Green, M.SC.

D. W. Cowling, B.SC.

PLANT PHYSIOLOGY

Head of Department: O. R. Jewiss,
B.SC., PH.D., A.R.C.S., D.I.C.

R. D. Williams, B.SC., PH.D.

EXTRA-MURAL STUDIES

H. K. Baker, B.SC., PH.D., DIP.AGR.

R. A. Redford (Assistant to Director in
Public Relations)

Secretary: I. A. Owen

BIOCHEMISTRY AND ANIMAL NUTRITION

Head of Department: W. F. Raymond,
M.A., A.R.I.C.

J. M. A. Tilley, B.SC., D.PHIL.

R. Milford, M.SC.

E. C. Jones, B.SC., F.R.I.C.

R. A. Terry, A.R.I.C.

R. J. Canaway, A.B.I.R.E.

ANIMAL AGRONOMY

Head of Department: F. E. Alder,
D.F.C., M.A., B.SC.

D. T. Chambers, M.SC.

J. C. Tayler, M.A., DIP.AG.

D. E. Eyles, M.SC.

GRASS/ANIMAL ECOLOGY

C. R. W. Spedding, M.SC., PH.D.

D. D. Kydd, M.A.

BIOMETRICS

C. D. Kemp, B.SC., DIP.STAT.

Librarian: E. W. Brennan Jones, M.A.

The Institute studies all aspects of herbage as food for ruminant animals, and the role in soil improvement of the grass/legume ley grown as part of a crop rotation.

At 31st March, 1960, the scientific and experimental staff numbered fifty.

CURRENT WORK

Plant and Soil Experiments

Herbage Agronomy. A wide range of plants is under observation, including exotic grasses of Mediterranean and sub-tropical origins which exhibit growth rhythms quite different from those of indigenous material. Some of the types under trial grow during the British winter. Seed supplies of these are being built up in order to make comprehensive grazing tests under various environmental conditions.

The role of nitrogen in pasture improvement has received further attention. This work is of immediate interest to the farmer because of the persisting

confusion about the uses of the nitrogen-collecting legume and of "bag" nitrogen in intensive grassland farming.

Herbicidal treatment of inferior grassland and the uses of various chemical plant-killers are also being studied. It now seems possible to kill selectively components of a mixed sward and to create new grassland without resorting to the plough.

Ley Agronomy. The ley is known to have an important influence on the level of yield in other crops in the rotation. This is due in part to residual soil nitrogen readily available for the next crop, and in part to other factors which include improved soil hygiene leading to a reduction of plant pests. Studies of irrigated leys have continued. The decomposition of plant debris in the soil is being investigated with particular regard to the nitrogen and carbohydrate cycles. Radioactive tracers are employed in this work.

Plant Physiology. Growth studies on the whole plant (root and top) are carried out under contrasting conditions of manuring and management. The physiology of roots and leaves is also studied. Flowering in pasture plants (grasses and legumes) receives attention, leading to a better understanding of the factors contributing to increased yields of herbage seed crops.

Studies involving the grazing animal

Animal Agronomy. Much of the work in this subject aims at finding improved techniques for keeping grazing animals thrifty during every month of the year and in the process the findings of other departments and disciplines are examined and integrated. Throughout these studies the herbage diet is evaluated in terms of the output of the meat-producing animal. A complete record is kept of animal performance from early life until slaughter and the resulting carcass is examined. The food intake of grazing animals is recorded and related to the class of pasture and the digestibility of its constituents.

Biochemistry and Animal Nutrition. The work in Animal Nutrition and that in Animal Agronomy are very closely linked. It now appears certain that contrasting herbages differ in digestibility when this is measured by experiments. Some of the biochemical differences can be attributed to the botanical composition of the sward and some to the growth stage of constituent plants when they are consumed by the animal. Ryegrass (S.23, S.24) is more digestible than cocksfoot (S.37), and related to this is the fact that these ryegrasses contain far more soluble sugars than cocksfoot.

Grass/Animal Ecology. The work in this department views the animal/plant/soil complex as a whole in the environment associated with high output and intensive grassland farming. The emphasis has been put on systems of fat lamb production in which an animal of high potential is used to measure pasture output. In some of this work the adverse effects of bowel parasites in lambs have been minimised by suitable control measures. Striking increases in output of meat per acre have resulted where animals known to be "worm-free" have been used in the experiments.

Biometrics. This department provides a computing and statistical advisory service for the Institute as a whole. Thus it is closely associated with the research programme of each individual department. It also carries out its own research aimed at the development of new and more precise techniques of pasture evaluation particularly in experiments with grazing animals.

Extra-mural Studies. These involve the planning of simple experiments which can be conducted on private and institutional farms throughout Britain. These experiments are based upon and are part of other experiments in progress at the Institute. They thus offer additional information which is of exceptional value to the headquarters research staff. Each major department makes use of the facilities offered by the extra-mural work so that herbage, animal and soil trials are in progress at a number of centres and in a wide range of environments.

The Annual Report of the Institute is published as "Experiments in Progress" which gives a full account of the researches being carried out.

HORTICULTURE, GLASSHOUSE CROPS AND FRUIT

JOHN INNES INSTITUTE

Bayfordbury, Hertford, Herts.

Director: K. S. Dodds, D.SC., PH.D.

GENETICS

Head of Department: J. R. S. Fincham,
B.A., PH.D.*

P. R. Day, B.SC., PH.D.

PLANT BREEDING

Head of Department: Watkin Williams, M.SC.

G. J. Dowrick, B.SC., PH.D.

N. E. G. Gilbert, B.A.

H. Williams, B.SC.

CELL BIOLOGY

Head of Department: H. Harris,

B.A., M.B., B.S., D.PHIL.φ

L. F. La Cour, M.B.E.

J. C. W. Crawley, B.SC.

J. McLeish, B.SC., PH.D.

N. Sunderland, B.SC., PH.D.

POTATO GENETICS

Head of Department: N. W. Simmonds,
M.A., A.I.C.T.A.

R. K. McKee, M.A., PH.D., A.I.C.T.A.

J. B. Harborne, B.SC., PH.D.

G. E. Marks, B.SC.

K. K. Pandey, M.SC., PH.D.

PHYSIOLOGY AND PLANT CULTURE

Head of Department: W. J. C. Lawrence,
O.B.E., V.M.H.

G. Hussey, B.SC., PH.D., A.R.C.S., D.I.C.

R. M. Whittle, B.SC., PH.D.

Secretary: G. R. Davies

* *Appointed 1st April, 1960.* φ *Appointed 1st June, 1960*

The work of the Institute is to study the principles of inheritance and the metabolism of cells, with the object of contributing to the improvement of agricultural and horticultural crops.

On 31st March, 1960, the scientific and experimental staff of the Institute numbered forty.

CURRENT WORK

The following are some items of interest from the year's investigations:—

The Genetics of Micro-organisms. Because of their rapid growth and the ease with which they can be handled, micro-organisms are now the favourite

experimental material for studies of the structure and function of genes and how they change and recombine spontaneously or under the influence of experimental treatments. In *Neurospora crassa* information about enzyme synthesis and the structure of the gene is being obtained by studies of the complementation patterns of a number of different mutants deficient in one enzyme. Similarly, the structure of the loci controlling sexuality in *Coprinus lagopus* is being analysed by the use of spontaneous and induced mutants. Heterozygous diploid strains of *Ustilago maydis* have been synthesised and mutagens used to stimulate mitotic crossing-over in them. By these means, information is being obtained on the nature of the process of recombination.

Selection of Parents and Family Size in the Breeding of Top-Fruits. Analyses of progeny records of many characters in the apple have now been completed. With a random set of heterozygous parents, characters governed by polygenic systems (e.g. mildew resistance, flavour, shape, size and colour of fruit and season of maturation) have mean F_1 values about equal to the mid-parental values, irrespective of the functional relationships between alleles and between genes. Hence, in a given set of crosses, the higher the parental means the greater is the likelihood of selecting progeny with high values. Thus progeny means may be predicted reasonably accurately and it has become clear that the choice of parents for any given combination of characters can be severely limited. Only parents with a high expression of the desired characters are likely to yield results that are commensurate with the efforts involved in hybridisation and testing.

The records also provide an estimate of the size of family required to give a reasonable chance of obtaining a satisfactory selection. The data suggest that segregates acceptable for the five characters (1) mildew resistance, (2) size of fruit, (3) season of maturity, (4) colour of skin and (5) flavour and texture occur with the following frequencies: 40, 20, 20, 10, 10 per cent respectively. Assuming independent assortment, a family of 6,250 plants would, on average, yield one individual having the required combination of these five characters. There is still a chance of missing the "winner" in one out of every three families. If this probability is reduced to one in twenty, the family size would have to be increased to about 18,750. If it were decided that, initially, at least five selections would be required from which to make the final selection, then the family size becomes 31,250. To handle such large numbers of adult fruit trees is an impossible task—one family would occupy 13 acres of land. If usable correlations between seedling and adult characters can be found, it should be possible to reduce family size very drastically at the seeding stage.

A report on the work of the Institute is published annually.

GLASSHOUSE CROPS RESEARCH INSTITUTE

Rustington, Littlehampton, Sussex

Director: F. W. Toovey, O.B.E., B.Sc., A.R.C.S., A.I.C.T.A.

PLANT BREEDING

L. A. Darby, B.Sc.

HORTICULTURE AND SCIENTIFIC LIAISON

Head of Department: G. F. Sheard, M.Sc.

PLANT PHYSIOLOGY

Head of Department: E. R. Leonard,

D.Sc., A.R.C.S.

A. J. Cooper, B.Sc., PH.D.

H. R. B. Hack, B.A.

PLANT PATHOLOGY DIVISION

Head of Division: L. Broadbent,
D.Sc., PH.D.

CHEMISTRY

Head of Department: G. W. Winsor,

B.Sc., PH.D., D.I.C., A.R.I.C.

J. N. Davies, B.Sc., PH.D.

P. B. Flegg, B.Sc., A.R.I.C.

ENTOMOLOGY

Head of Department: N. W. Hussey,
B.Sc., PH.D.

STATISTICS

D. Cooke, M.A., DIP.STAT.

MYCOLOGY

Head of Department: P. H. Williams, B.Sc.

CROP PROTECTION

Head of Department: W. H. Read,

M.Sc., F.R.I.C.

VIROLOGY

Head of Department: M. Hollings, B.Sc.

Nursery Manager: J. M. Evans, N.D.H.

Secretary: J. Bishop, A.C.I.S.

Librarian: Miss G. Dunster, B.A.

The Institute was established in 1953 to undertake research bearing on the cultivation of glasshouse crops and mushrooms, and of bulbs, flowers and shrubs grown in the open. The development of the Institute was carried a stage further during the year, and much time was spent planning research facilities still required. An Administration Block, which also accommodates the library and provides a conference room for meetings, was completed by the end of the year.

On 31st March, 1960, the scientific and experimental staff numbered thirty-four.

CURRENT WORK

Plant Breeding. The tomato breeding programme has made excellent progress, and some of the material undergoing trial, either at the institute, at the M.A.F.F. Experimental Horticulture Stations, or on selected commercial nurseries, has aroused considerable interest among growers. There is no doubt that an improved variety would make a very valuable contribution to the industry in assisting it to meet competition arising from the import of good quality fruit from abroad. The "Baby Lea" crosses with compact habit are particularly promising, and some families derived from the cross "Baby Lea" $\times$ "E.S.5" yield very attractive fruit. Earliness of cropping is a character of prime importance in assessing the new material, and in the trials conducted in 1959 it is satisfactory to note that all varieties averaged about 1 lb. per plant picked in April.

The lettuce and cucumber programmes have continued, and good progress is being made in producing a winter lettuce with paler green leaves from crosses

of "Cheshunt 5B" with lighter coloured varieties. Large F_2 families from these crosses were grown at the Institute and also at the M.A.F.F. Experimental Horticulture Station at Fairfield in Lancashire, selections being made and F_3 seed produced.

Plant Physiology. The basic study of tomato growth has revealed a very interesting phenomenon of considerable practical significance. Experiments in which seed was sown at various times during the year have shown that there is what might be termed a "dormant" period when the plant makes no progress in certain aspects of its development, and this period seems to be determined not only by the daylength but also by whether the daylength is increasing or decreasing. The "dormant" period occurs from a date in October until about the shortest day, and its existence explains the difficulty that growers experience in setting the first truss as the planting date is advanced in an attempt to obtain earlier cropping.

Environmental observations in the special purpose glasshouse have continued, and a study has been made of the accuracy obtainable in the integration of solar radiation by methods developed at the Institute.

Chemistry. Investigations during 1959 were again primarily concerned with the nutrition of glasshouse crops and the composition and biochemistry of tomato fruit. The problem of manganese toxicity in glasshouse soils, which seems to be increasing in importance, has also received attention, and techniques for studying another common problem of glasshouse soils, that of excessive salinity, have been further investigated. Preliminary experiments have been carried out on loamless composts.

The nutritional studies included four experiments with tomatoes, two of which were concerned with fertilisers applied in solution, a factorial experiment with two varieties of carnation, and experiments on winter lettuce.

Studies on the composition of tomato fruit have included both the use of specialised techniques for the separation and determination of individual organic acids and the application of rapid routine procedures for the assessment of fruit quality. Investigation of the pectic enzymes in tomato fruit have shown interesting differences in the pectin methylesterase activity and the proportion of soluble pectic substances in "normal" and "blotchy" areas of tomatoes.

The main developments in mushroom research undertaken in the Chemistry Department have been the construction of equipment for studies of mushroom growth under controlled environmental conditions, and preliminary work on the measurement of moisture stress in casing materials and composts.

Statistics. Special problems which have engaged the attention of the statistician have been the timing of harvests in horticultural experiments and the investigation of the cause of the high standard error in mushroom experiments. As part of the studies on the influence of time of harvesting on the yield of a crop, the growth rate of a crop of mushrooms was determined.

Entomology. Continuing the work on mushroom pests, tests of contact and vapour repellents against adult Phorids were conducted, as well as on methods for reducing the scale of natural infestations which take place during spawn running. The work on Cecids has ranged over a wide field, and has included experiments on their spread and migration and on their control by means of insecticides. With the Glasshouse Red Spider Mite (*Tetranychus*

urticae) studies have been made on the specific status of the British and American colour forms by cross-breeding experiments carried out on a larger scale and in greater detail than previously. A preliminary study has been made of the Agromyzid leaf-miners of ornamental crops.

Mycology. Work has proceeded on all the problems previously mentioned in these reports, and in addition, a new disease of polyanthus, which causes stunting, yellowing of the leaves and eventual death, has been investigated. With the mushroom disease often referred to as "Watery Stipe" clear evidence has been obtained of its transmissibility both in cultures in the laboratory and in beds in a growing house. The nature of the infectious agent is still uncertain, but the possibility that it may be a virus, for which there seems to be some evidence, is being explored.

Virology. With the setting up of a Department of Virology an extensive programme of work on horticultural crops within the Institute's terms of reference has been initiated. The disease caused by tobacco mosaic virus infection of tomatoes, which is recognised to be one of the major problems of the tomato grower, is receiving intensive study as there is still much that is not known about it. At this stage the experiments are primarily concerned with determining the main sources of infection. The virus diseases of a wide range of ornamental crops are also being investigated, with particular attention to those of the carnation and chrysanthemum. With the carnation, fourteen commercially important varieties have been indexed for their virus diseases, and preliminary experiments have been made to investigate the possibility of eliminating these diseases by the methods of tip culture and heat treatment. Four specific viruses of the chrysanthemum have been under investigation, with a special study being made of American stunt virus which has recently assumed prominence in this country and is a real danger to the chrysanthemum industry.

Crop Protection. Further work has been done on the control of *Didymella* Stem Rot of the tomato with captan, and the examination of the fungitoxic activities of derivatives of halogenated salicylaldehydes, principally in the control of Cucumber Mildew, has been concluded. The control of Glasshouse Red Spider Mite continues to receive attention, and trials have been carried out to determine the relative values of a number of newer systemic compounds for the control of the pest on carnations. An important new line of study is soil sterilisation, and a long-term experiment has been laid down to compare the chemical sterilising agents, chloropicrin and sodium N-methyldithiocarbamate ("metham-sodium"), with the traditional steaming. Problems associated with the use of "metham-sodium" are receiving particular attention. Preliminary work has also been done on the control of leaf diseases of narcissus which are a trouble to bulb growers in the south-western part of the country and in the Scilly Islands.

Horticulture. A new Department has been set up to undertake experiments of a horticultural nature with a view to defining the problems needing attention by the specialist Departments and for testing the results from those Departments in the first stage of their application to glasshouse practice. Work has begun on plant density studies with carnation, and on loamless composts. In conjunction with the Statistics Section a survey was made of tomato varieties grown under glass in Great Britain as a guide to the planning of future experiments.

A fuller account of the Institute's work is published in its Annual Report.

EAST MALLING RESEARCH STATION

East Malling, Maidstone, Kent

Director: F. R. Tubbs, C.B.E., M.Sc., Ph.D., A.R.C.S., D.I.C., F.L.S.

Advisers to Director: T. N. Hoblyn, O.B.E., Dip.Hort.
R. V. Harris, D.Sc., A.R.C.S., D.I.C.

Assistant to Director: H. B. S. Montgomery, B.A., Ph.D., D.I.C.

POMOLOGY

Head of Department: W. S. Rogers,
M.A., D.Sc., Dip.Hort., A.Inst.P.

Miss A. B. Beakbane, Ph.D., N.D.H.

R. M. Fulford, B.Sc.

R. J. Garner, M.Sc., N.D.H., Dip.Hort.

R. L. Knight, O.B.E.,

D.Sc., A.I.C.T.A., Dip.Agric.

Miss I. Modlibowska, Ph.D.

Miss B. G. Mosse, Ph.D., Dip.Hort.

STATISTICS

Head of Department: S. C. Pearce, Ph.D.

G. H. Freeman, M.A., Ph.D., Dip.Stat.

P. Sprent, B.Sc.

PLANT PHYSIOLOGY

Head of Department: H. W. B. Barlow,
B.Sc.

C. R. Hancock, B.Sc.

E. S. J. Hatcher, Ph.D.

F. W. M. Llewelyn, Ph.D., A.R.C.S.

D. H. Maggs, B.Sc.

BIOCHEMISTRY

Head of Department: A. E. Flood,
M.A., Ph.D.

Secretary: R. L. Oxley

FRUIT NUTRITION

Head of Department: D. W. P. Greenham,
M.A., Ph.D.

M. Allen, B.Sc.

Miss A. V. Delap, B.A., Ph.D.

Miss E. M. Ford, Ph.D., A.R.C.S.

J. E. Goode, B.Sc.

PLANT PATHOLOGY

Head of Department: A. F. Posnette
M.A., Sc.D., Ph.D., A.I.C.T.A.

Deputy Head: J. E. Crosse, B.Sc., Ph.D.

R. Crompton, N.D.H. (Hons.), Dip.Hort.

D. S. Kirkham, Ph.D.

J. T. Legg, B.Sc.

M. H. Moore, M.Sc., Ph.D., Dip.Hort.

G. W. F. Sewell, Ph.D.

P. W. Talboys, Ph.D., D.I.C.

ENTOMOLOGY

Head of Department: G. H. L. Dicker,
Ph.D., A.R.C.S.

Miss E. Collyer, Ph.D.

A. M. Massee, O.B.E., D.Sc.

R. C. Muir, B.Sc.

R. S. Pitcher, Ph.D., Dip.Agric., Dip.Ento.

PLANT PROTECTIVE CHEMISTRY

Head of Department: A. H. M. Kirby,
M.Sc., Ph.D., F.R.I.C.
R. P. Tew, F.R.I.C.

SCIENTIFIC LIAISON

Head of Department: H. B. S. Montgomery,
B.A., Ph.D., D.I.C.

Librarian: S. R. Ball, B.A., F.L.A.

East Malling Research Station, which owes its foundation in 1913 to the enterprise of the old South Eastern Agricultural College at Wye and the fruit growers of Kent, is concerned with problems arising out of the culture of fruit plants in the field. Its work has been helped forward by the continued support of the Industry and the State, which has enabled the experimental farm, as well as the laboratories, to be extended. Recent evidence of this has been the addition of 140 acres of land, without cost to the State, which will ensure that efficient field experiments can continue for the next 25 years at least. Much work is concerned with diseases and pests, both of fruit and of hops, and is directed towards their control. A special feature is the selection, testing and propagation of healthy plants as a source of clean pedigree material for the fruit industry.

On 31st March, 1960, the scientific and experimental staff numbered eighty.

The first of the two main parts of the book is devoted to a general survey of the various theories of the origin of life, and the second part is devoted to a detailed examination of the various theories of the origin of life, and the third part is devoted to a detailed examination of the various theories of the origin of life.

The first of the two main parts of the book is devoted to a general survey of the various theories of the origin of life, and the second part is devoted to a detailed examination of the various theories of the origin of life, and the third part is devoted to a detailed examination of the various theories of the origin of life.

The first of the two main parts of the book is devoted to a general survey of the various theories of the origin of life, and the second part is devoted to a detailed examination of the various theories of the origin of life, and the third part is devoted to a detailed examination of the various theories of the origin of life.

The first of the two main parts of the book is devoted to a general survey of the various theories of the origin of life, and the second part is devoted to a detailed examination of the various theories of the origin of life, and the third part is devoted to a detailed examination of the various theories of the origin of life.

The first of the two main parts of the book is devoted to a general survey of the various theories of the origin of life, and the second part is devoted to a detailed examination of the various theories of the origin of life, and the third part is devoted to a detailed examination of the various theories of the origin of life.

constant study. For apples and pears, the crop in the two years preceding the start of an experiment is often a useful measure, and so is trunk girth at the start. By the use of double co-variance, the error variance in the subsequent experiment may be halved.

AGRICULTURAL AND HORTICULTURAL RESEARCH

Long Ashton, Bristol

Director: Professor H. G. H. Kearns, O.B.E., B.Sc., Ph.D. DIP. AGRIC.

Assistant Directors: R. W. Marsh, M.A.

J. T. Martin, D.Sc., Ph.D., F.R.I.C.

POMOLOGY AND FRUIT BREEDING

Head of Section: L. C. Luckwill,
B.Sc., Ph.D.

D. L. Abbott, B.Sc.
R. R. Williams, B.Sc., DIP.HORT.SCI.
D. Wilson, B.Sc., Ph.D.

NUTRITION OF FRUIT CROPS

Head of Section: C. Bould, M.Sc., Ph.D.

R. A. Webb, B.A., D.PHIL.
D. G. Hill-Cottingham, M.Sc., Ph.D., A.R.I.C.

ANALYTICAL AND GENERAL CHEMISTRY

Head of Section: J. T. Martin,
D.Sc., Ph.D., F.R.I.C.

E. Somers, M.Sc., Ph.D.
E. J. Skerrett, Ph.D., A.R.I.C.

ORGANIC CHEMISTRY

Head of Section: D. Woodcock,
D.Sc., Ph.D., F.R.I.C.

PHYSICAL CHEMISTRY

Head of Section: W. D. E. Thomas,
B.Sc., Ph.D., F.R.I.C.

C. P. Lloyd-Jones, B.Sc., A.R.I.C.

PLANT BIOCHEMISTRY

Head of Section: H. E. Davenport,
B.Sc., Ph.D.

CHEMICAL MICROBIOLOGY

Head of Section: D. J. D. Nicholas,
D.Sc., Ph.D., A.K.C., F.R.I.C.

PLANT PHYSIOLOGY

Head of Section: E. J. Hewitt,
B.Sc., Ph.D., A.K.C.

PLANT CONSTITUENTS

Head of Section: A. H. Williams,
B.Sc., M.A.

Secretary: A. L. Leggett, F.C.A.

* Died 29th May, 1960

ENTOMOLOGY

Head of Section: H. G. H. Kearns,
O.B.E., B.Sc., Ph.D., DIP.AGRIC.

S. H. Bennett, B.Sc., Ph.D.*
N. G. Morgan, B.Sc., Ph.D.
A. Stringer, B.Sc., A.R.C.S.
C. G. L. Furnidge, B.Sc., Ph.D., A.R.I.C.
T. E. Cobbald, B.Sc., G.I.MECH.E.
H. R. Mapother, B.A., B.Sc., A.R.I.C.

PLANT PATHOLOGY

Head of Section: R. W. Marsh, M.A.

R. J. W. Byrde, B.Sc., Ph.D.
A. T. K. Corke, B.Sc., Ph.D.

CIDER AND FRUIT JUICES

Head of Section: A. Pollard, M.Sc., Ph.D.

G. C. Whiting, B.Sc., Ph.D.
L. F. Burroughs, B.Sc., Ph.D., A.R.I.C.
F. W. Beech, B.Sc., Ph.D., A.R.I.C.
Miss M. E. Kieser, B.Sc., A.R.I.C.
C. F. Timberlake, M.Sc., Ph.D., A.R.I.C.
J. G. Cart, B.Sc., Ph.D.

DOMESTIC FOOD PRESERVATION

Head of Section: Miss B. A. Crang, B.Sc.†

WILLOWS

Head of Section: K. G. Stott, B.Sc.

STATISTICS

Head of Section: G. M. Clarke,
M.A., F.R.S.S., DIP.STAT.

SCIENTIFIC LIAISON

Head of Section: M. Greenwood,
O.B.E., M.Sc.

PLANTATIONS AND GREENHOUSES

Head of Section: E. W. Hobbis,
M.B.E., B.Sc., N.D.H.

Librarian: P. R. Colegate

† Died 1st April, 1960

A.R.C. UNIT OF PLANT NUTRITION (MICRO-NUTRIENTS)

Long Ashton, Bristol

(Disbanded 30th September, 1959)

Honorary Director: Professor T. Wallace, C.B.E., M.C., D.Sc., F.R.I.C., V.M.H., F.R.S. (Emeritus Professor of Horticultural Chemistry, Bristol University)

PLANT PHYSIOLOGY

E. J. Hewitt, B.Sc., Ph.D., A.K.C.

NUTRITION OF MICRO-ORGANISMS

D. J. D. Nicholas, D.Sc., Ph.D., A.K.C.,
F.R.I.C.

PLANT BIOCHEMISTRY

H. E. Davenport, B.Sc., Ph.D.

ORGANIC CHEMISTRY

A. H. Williams, M.A., B.Sc.

INORGANIC CHEMISTRY

H. M. Stevens, B.Sc., Ph.D.

SOIL BIOLOGY

R. A. Webb, B.A., D.Phil.

The Station, which is administered by the University of Bristol, studies all aspects of fruit growing, with special reference to the problems of growers in the West Midlands and the South-West. It also undertakes research and advisory work on cider, perry and fruit juices, on the domestic preservation of fruit, vegetables, meat and poultry, and on the cultivation and utilisation of willows. In addition, the Station advises the Colonial Office on trace element deficiencies and on spray techniques for the control of pests and diseases of tropical crops.

On 31st March, 1960, the scientific and experimental staff numbered eighty.

CURRENT WORK

The scope of the Station's research was enlarged by the transfer to the staff of the former members of the A.R.C. Unit of Plant Nutrition (Micro-nutrients), disbanded on 30th September, 1959. The majority were allocated to newly-formed chemical Sections.

In work on the improvement of fruit plants, the breeding programme has been concentrated on black currants. The collection of *Ribes* species now assembled provides a pool of genetic characters, and a promising high-yielding early variety is now ready for extended trials.

In view of the virus infection of many of the vegetatively-propagated apple rootstocks, trials are being made with the uniform seedling rootstocks provided by the apomictic *Malus sikkimensis* and *M. toringoides*. Such seedlings, raised in 1950, were budded in 1952 with Worcester Pearmain, Lord Lambourne and Cox's Orange Pippin. Up to 1959 the performance of Worcester on the apomictic seedling rootstocks has been unsatisfactory, but Cox has made a vigorous tree on *M. sikkimensis* and given a better crop than on M.II. Lambourne has given a small tree but a heavy crop on the apomictic stocks: this suggests the possibility of growing a healthy, semi-dwarf, prolific tree of this virus-susceptible variety.

Studies on chemical thinning of apple crops have been made with naphthalene acetamide applied at petal fall for three successive years on the same branches. Spraying in 1957 greatly reduced the number of small fruits

and slightly increased that of large ones. In the next year there were more blossoms on the 1957 sprayed branches than on the controls and, following the 1958 spray, there were again fewer small and more large fruits. In 1959, however, the unsprayed branches bloomed more profusely than the sprayed and set a good crop of well-sized fruit: the effect of the 1959 spraying was to reduce the numbers of both small and large fruits. The tentative conclusion is that the indiscriminate use of this chemical thinning spray year after year cannot be recommended. The choice of appropriate years for such sprays will depend on the possibility of early-season forecasting of the crop.

A comprehensive survey of the use of selective weed-killers in fruit plantations has been undertaken, with special reference to problems of phytotoxicity, and to the control of grass around tree trunks.

Further investigations into the biology of the black-currant gall-mite (*Phytoptus ribis*) have shown that mites start to leave the enlarged buds in March, in search of more humid quarters. As new buds are not formed until early April, the mites that emerge too early are killed by desiccation. Migration to the new buds continues until June. Mites can jump upwards and frequently become airborne in windy weather: they are also carried by aphids, flies and many other insects, and can be washed down by rain to the new buds at the crown of the bush. Experiments to arrest mite migration by successive applications of relatively weak sulphur sprays are in progress.

The formation and deposition of the "low-volume" sprays produced by mist-blowers is being jointly studied by entomologists, mycologists, chemists, physicists and designers of spray machinery. An electronic particle resolver has been installed for the study of spray droplet spectra. The accuracy of the fluorescent-tracer technique for plotting spray deposition on foliage has been established, and the method has recently been applied in assessing results of the spraying of cigar-wrapping tobacco in Borneo. A hand pneumatic sprayer for treating the spadices of coconuts has been specially designed for the use of the operators who climb the trunk of the coconut palm.

Work on the utilisation of surplus apples by the production of opalescent apple juice continued to attract widespread interest. Detailed studies were made of the effect of processing methods on the quality of the product, particularly on its ascorbic-acid content. Using English culinary and dessert varieties, batches of opalescent apple juice were made on a semi-manufacturing scale. Blends with orange, pineapple and apricot were prepared and proved highly acceptable.

The domestic food preservation section is giving special attention to the bacteriological problems arising from the extending use of deep-freeze units, and to the effects of fungicides and insecticides in inducing taints in processed fruits.

A survey of basket-willow growing has shown a continuing shrinkage in willow acreage since 1957, the Somerset total being now only 1,200 acres. Because of the shortage of basketmakers in this country, the English growers have not benefited from the present high demand for basketware, almost all of which is imported. In the attempt to increase the popularity of home-grown willows, a scheme for the production of standardised bundles has now been introduced in Somerset.

The chemical microbiology section has continued investigations into enzymes concerned in denitrification of nitrates to nitrite, nitric oxide and nitrogen gas. These enzymes have been characterised in soil bacteria; thus, an active dissimilatory nitrate reductase, purified more than 100-fold from *Pseudomonas aeruginosa*, was shown to require reduced diphosphopyridine nucleotide as an electron donor and to contain flavin adenine dinucleotide, cytochrome c, molybdenum and sulphhydryl groups as functional constituents. A nitrite reductase, purified 600-fold from the same soil bacterium, was shown to utilise a range of electron donors including reduced flavins and reduced dyes. The enzyme contains cytochrome c, copper, sulphhydryl groups and requires either phosphate or sulphate for maximal activity. Nitrite is reduced to nitric oxide by the enzyme. A nitric oxide reductase, purified 20-fold from the *Pseudomonas*, is an iron dependent flavo-protein which utilises a number of electron donors. Nitrogen gas is the reduction product.

A noteworthy advance has been made in studies with soil bacteria that fix atmospheric nitrogen, since cell-free extracts have now been prepared from *Azotobacter vinelandii* that incorporate substantial amounts of the stable isotope, nitrogen-15. This is probably one of the first records of a fixation of nitrogen in a cell-free extract of a micro-organism. A new technique has also been developed in collaboration with the M.R.C. Radiotherapeutics Unit, Hammersmith Hospital, for the use of radioactive nitrogen-13 (Cyclotron product, half life 10 min.) to study the mechanism of biological fixation of nitrogen in bacteria, algae and root nodules.

A detailed account of the work and publications of the Research Station is given in its Annual Report.

SCOTTISH HORTICULTURAL RESEARCH INSTITUTE

Mylnefield, Invergowrie, Dundee

Director: T. Swarbrick, M.Sc., Ph.D.

VIROLOGY

Head of Department: C. H. Cadman,
B.Sc., Ph.D., F.R.S.E.

C. E. Taylor, B.Sc., Ph.D.
R. M. Lister, B.Sc., Dip.Agric.Sc., D.T.A.

VEGETABLE CULTURE

Head of Department: C. North, M.Sc.,
Ph.D., N.D.A.

POMOLOGY

Head of Department: C. A. Wood,
B.Sc., Ph.D.

D. L. Jennings, B.Sc.

PHYSIOLOGY

Head of Department: C. G. Guttridge,
B.Sc., Ph.D.

MYCOLOGY

Head of Department: A. R. Wilson,
B.Sc., M.Sc., Ph.D.

W. R. Jarvis, B.Sc., Ph.D., D.I.C.

GENETICS

Head of Department: G. M. L. Haskell,
B.Sc., Ph.D.

A. B. Wills, B.Sc.

WEST OF SCOTLAND UNIT

Auchincruive, Ayr.

R. D. Reid

Miss I. G. Montgomerie, B.Sc., Ph.D.

Secretary: A. B. Ross, F.C.C.S., A.I.A.C.

This report mentions only some of the more outstanding recent developments in the fields of virology, plant physiology and plant breeding. A more detailed account of the work of the Institute is to be found in its own Annual Report.

On 31st March, 1960, the scientific and experimental staff numbered twenty-nine.

CURRENT WORK

Facilities for studying the physiology of the strawberry plant have been greatly improved in the last two years. From evidence now available it is concluded that production of flowers and runners is controlled very largely by fluctuations in the concentration of a hormone produced in mature strawberry leaves in response to daylight. This hormone has properties like those of the gibberellins, and its main effects are to stimulate runner production and inhibit flower formation. More of it is produced in long days than in short, and this finding provides a reasonable explanation of the observed sequence of runner and flower initiation in the commercial strawberry varieties grown in this country. The everbearing varieties are not so closely controlled. More work is required for a proper understanding of the control mechanism. Advancement of knowledge in this field may provide a basis for controlling flower and runner production in commercial practice.

Work on soil-borne viruses has continued and it has been shown that diseases caused by these viruses occur not only in the raspberry and strawberry crops of Scotland, but in a range of other crops, including potatoes, sugar beet and vines. These diseases have now been identified in crops from various centres in Britain, Continental Europe and North America. This has been done by the use of antisera prepared at Mylnefield and supplied to other workers on an experimental basis. Until recently little was known of the mode of spread and of the way in which infectivity is maintained in a soil. Investigations have now shown that some, though not all, of these viruses can be transmitted through seeds and also that eelworms can transmit the viruses from plant to plant. These discoveries should make possible a more intelligent approach to the control of these viruses.

The Institute's strawberry breeding work is now well known. The development of "yellows" in the variety Climax resulted in this variety becoming no longer profitable. Despite five years' fairly intensive investigation the exact cause of this malady has not been found. The effort put into this investigation is now being directed elsewhere, particularly as the plant breeders have found a practical means of avoiding the high incidence of "yellows," that was general five or six years ago. New genotypes have been introduced into the breeding programme, and some promising seedlings from crosses made in 1958-59 are now undergoing field tests.

The two varieties Talisman and Red Gauntlet, bred and introduced by the Institute, have become established commercial varieties in Great Britain, Holland and Belgium. The variety Talisman has received an Award of Merit from the Royal Horticultural Society.

Although grey mould, *Botrytis cinerea*, was less in evidence this year, the dry season made it easier to study the factors which favour outbreaks of the disease in raspberry and strawberry. The results have shown that whilst much depends on differences in varietal susceptibility and in cultural practices, effective chemical control may not be impracticable. A new approach is being made to the troublesome problem of dieback in Malling Promise and other raspberry

varieties. There is some indication that fungal attack on the roots may be involved but this is not yet established.

The cytology and genetics of *Rubus* and *Ribes* species have become a major interest of the Genetics Department and information from these studies is aiding the progress of plant breeding in the Pomology Department. The first results from the black currant seedlings bred during the past four years are highly encouraging and there seem good prospects of producing varieties whose berries ripen evenly on the strig. Experiments on raspberry cultivation continue, and the manurial trials have given striking evidence of the response of raspberries to nitrogen. The use of chemical herbicides may solve the problem of weed control in raspberries. The most promising chemicals, however, are persistent in soils and the effects of cumulative doses on plant growth are being examined. Apples did well again this year, and the results of the trials suggest that apple-growing in eastern Scotland may have distinct practical possibilities.

The enthusiastic response to a conference, organised last autumn on the production of vegetables for canning and quick-freezing in Scotland, is perhaps a measure of the interest created by the work of the Vegetable Crops Department. Many strains of vegetable varieties have been assessed during the past few years, and the results have provided Scottish growers with authoritative information. Breeding of Brussels sprouts, cabbages and dwarf beans was continued, and some selections of each are beginning to show commercial merit.

WYE COLLEGE

Department of Hop Research

Wye College (University of London), Ashford, Kent

Head of Department: H. S. Darling, B.SC., M.AGR., PH.D., A.I.C.T.A.

Senior Scientific Staff:

F. C. Thompson, B.SC., M.SC.(AGRIC), A.R.I.C. R. A. Neve, B.SC.(AGRIC.), DIP.AGRIC.SCI.

Hop research at Wye College continues to cover the majority of problems involved in the production of the hop crop; research on hop virus diseases and *Verticillium* wilt is carried out by East Malling Research Station. The main lines of work at Wye are plant breeding, chemistry, plant nutrition, pest control, downy mildew disease (*Pseudoperonospora humuli*), hop growth, and investigations on hop picking and drying. This work is supported by an extensive programme of field experiments. Research on hop engineering problems, including the performance of wirework systems, is carried out in collaboration with the National Institute of Agricultural Engineering. On 31st March, 1960, the scientific and experimental staff of the Department numbered nine.

CURRENT WORK

The chief aim of hop breeding continues to be the production of commercially acceptable wilt-tolerant varieties. East Malling Research Station collaborates in this work and three promising diploid seedlings, intended to provide a tolerant substitute for the popular but wilt-sensitive Fuggle, are now undergoing farm trials. Further series of diploid and triploid material are coming forward for

trial and for selection on criteria which include disease resistance and suitability for mechanical picking and for lager brewing. Selection within existing clonal strains of Goldings and Fuggles continues with the object of providing improved stocks for use by growers who are fortunate enough to remain free from progressive wilt.

Chemical research includes the examination of many samples of cones for soft resin content in support of all aspects of department work. It is hoped that in future cones will also be analysed for essential oils which, though less than one per cent of dry hops by weight, contribute much to aroma and brewing flavour. This work on hop oils is expected to help plant breeders in selecting hop varieties for specific purposes including lager brewing. Hop chemistry is also concerned with the mineral nutrition of the plant. Here replicated manurial trials provide yield data which are used to calibrate the results of routine soil and leaf analyses.

Work on downy mildew disease is making good progress and results indicate that the disease overwinters as a mycelium in the rootstocks of infected plants. No evidence has yet been found to show that winter spores are of importance in the annual cycle of the disease. Results of current work also indicate that dusting rootstocks with Bordeaux powder during the growing season may give considerable protection from downy mildew if carried out with disease-free planting material. Research on the assessment of field resistance to the disease continues in support of plant breeding work.

Studies on carbohydrate food reserves in rootstocks have continued and have shown that in young plants the rapid growth made in spring and early summer is maintained by food accumulated in the previous autumn. For the remainder of the summer, food is used as fast as it is produced and accumulation of reserves for use in the winter and the following season does not occur until the autumn. This work is being extended to mature plants. Mist propagation of hops, which was pioneered at Wye College, is gaining in popularity among commercial growers and research is now concerned with finding how this intensive glasshouse technique can be fitted efficiently into the cycle of a farm crop.

The new replicated height of wirework and spacing trial was harvested for the first time in 1959; half of each plot was picked by hand and half by machine to give a comparison of the accuracy of the two methods. The use of the machine did not appear to introduce major errors in yield data and the effects of different treatments were demonstrated consistently by both harvesting methods. This trial is also being used for growth studies and for measurements by recording dynamometers of strains and stresses in hop wirework. Research on wirework systems also includes estimations of the yield loads of hop anchors.

Work study research has begun on methods of transporting bines from the field to the picking machine. These investigations are associated with research on the safe and economic disposal of *Verticillium*-infected waste material from hop picking machines in progressive wilt areas.

VEGETABLES

NATIONAL VEGETABLE RESEARCH STATION

Wellesbourne, Warwick

Director: James Philp, B.SC., PH.D.

Deputy Director: D. W. Wright, M.A.

Senior Scientific Staff:

PLANT BREEDING

Head of Department : J. C. Haigh,
B.SC., PH.D., A.R.C.S., A.I.C.T.A.

H. Holland, B.SC.

A. G. Johnson, B.SC., PH.D.

L. E. Watts, B.SC.

CHEMISTRY

Head of Department : F. Haworth,
B.SC., PH.D., DIP.AG.SC., A.R.I.C.

S. P. Spragg, B.SC., PH.D.

PHYSIOLOGY

Head of Department : E. J. Winter,
M.C., M.SC.

R. B. Austin, B.SC.

J. K. A. Bleasdale, B.SC., PH.D.

IRRIGATION

Head of Department : E. J. Winter,
M.C., M.SC.

P. J. Salter, M.SC.HORT., PH.D.

Secretary: G. Lesson, B.SC.(ECON.), A.C.I.S.

ENTOMOLOGY

Head of Department : D. W. Wright, M.A.

T. H. Coaker, B.SC., D.I.C.

J. A. Dunn, M.SC., PH.D.

G. A. Wheatley, B.SC.

PATHOLOGY

Head of Department : W. G. Keyworth,
B.SC., PH.D., A.R.C.S., D.I.C.

A. G. Channon, B.SC.

R. B. Maude, B.A., M.SC.

J. A. Tomlinson, B.SC., PH.D.

WEEDS

Head of Department : H. A. Roberts,
B.SC.

STATISTICS

Head of Department : J. A. Nelder, M.A.

Librarian: D. A. Woodroffe, B.SC.

The Station and Sub-Station at Paglesham, Essex, were established in 1949. Work is concerned with a wide range of important practical problems in many vegetable crops, and with obtaining scientific knowledge which will lead to advances in the practice of vegetable production. There are eight research sections which deal with the breeding of improved varieties, the improvement and maintenance of soil fertility, the investigation of factors affecting crop growth, the study of irrigation, the control of pests, diseases, and weeds, and the improvement of field experimentation.

On 31st March, 1960, the scientific and experimental staff of the Station numbered forty-two.

CURRENT WORK

Plant Breeding. Breeding work is in progress with 12 vegetable crops. With culinary peas there is a need for an early-maturing variety of good quality which would extend the relatively short season. Increased earliness entails autumn sowing but existing varieties seldom survive the winter. Crosses

have been made, however, between the extremely winter-hardy, round-seeded but poor quality Austrian winter maple pea, and non-winter-hardy, wrinkled-seeded culinary varieties of good quality. Natural selection for winter hardiness took place in successive generations and winter-hardy, wrinkled-seeded F_4 's have been obtained which mature three to four weeks earlier than the earliest spring-sown varieties; peas from these lines are now being tested for quality.

Chemistry. Long-term cultivation and manuring experiments have completed the second cycle of a three-year crop rotation of vegetables, and have continued to provide interesting results. Another study in progress indicates that the concentration of oxygen in the soil must be reduced to a very low level to cause inhibition of the aerobic and nitrifying activities of the soil organisms, or to induce anaerobic metabolic and denitrifying processes.

Plant Physiology. Field studies have been continued on the effects of spatial arrangements of plants on crop yield, and on the ability of the crop to compete with weeds. Three years' results with carrots have shown that rows spaced 12 inches apart gave superior yields to rows spaced 24 inches apart, the number of plants per square foot being the same in each treatment. Similar work with red beet during 1959, however, showed that these row spacings did not affect the final yield in November. Delaying the first weeding of onions for two weeks has usually reduced the yield by about 10-20 per cent but in the dry summer of 1959, which lowered the general yield level, the delayed weeding reduced the yield by 44 per cent, even although there were only 2.5 weeds per foot of row at weeding time,

Farmyard manure has produced much greater increases in yields of both carrots and red beet than any of the fertiliser treatment tested at Wellesbourne. Growth studies have shown that FYM had a striking effect during the very early stages of growth of both crops, i.e., during the first five weeks when the relative leaf growth rates and net assimilation rates were much greater in plants on the plots having had FYM. These effects on growth were not maintained during the subsequent period of growth, but the absolute growth rates were always greater with FYM.

Irrigation. Investigations on the irrigation of various vegetable crops are in progress and emphasis is being laid on determining moisture-sensitive stages during the life of a crop with the object of improving crop production by the most economical use of water supplies. With the pea variety Dark-skinned Perfection, additional application of water between sowing and flowering time did not increase the yield of peas although it increased the amount of haulm, whereas additional water supplied when the pods began to swell did increase the yield of peas. Studies have also been continued on the effects of varying the droplet size of irrigation water, the use of weather factors to provide "time scales" for growth analysis, various aspects of the different methods of determining soil moisture characteristics, and on the process by which whole root systems absorb water and nutrients.

Entomology. Work has been continued on the biology and control of several pests of vegetable crops. Special attention is being paid to the persistence of insecticidal residues in the soil, their effects on insect pests and their predators, and their uptake by succeeding vegetable crops.

Plant Pathology. Studies are in progress with a number of diseases of vegetables. In leaf and pod spot disease of peas (*Mycosphaerella pinodes*),

it has been found that treatment of heavily infected seed with captan has considerably reduced the percentage of infected seeds and the mechanism of the effect is now being investigated. Evidence has shown that big vein disease of lettuce is widespread in England and a study is being made of the *Olpidium* fungus found to be present in the roots of diseased plants.

Weeds. Ecological studies of weeds in vegetable crops in relation to cultural treatments have shown, among other things, that repeated vegetable cropping with the concomitant cultivations reduced the population of viable weed seeds in the soil of very weedy corn land to about half after the first year, to about one-fifth after the second year, and gave progressively smaller reductions in succeeding years. Ploughed plots contained less seed of annual meadow grass (*Poa annua*) than rotavated plots. The chemical amoben has given promising results when used as a residual pre-emergence herbicide with certain vegetable crops. Chlorpropham gave excellent control of chickweed (*Stellaria media*) and annual meadow grass throughout the winter in autumn-sown onions. Studies of the type and severity of injury symptoms induced by spray drift of MCPA and 2,4-D on vegetable crops have been continued.

Statistics. Investigations have shown that certain cultural factors had a marked effect on the accuracy of field experiments with vegetables and that there were other highly complex factors which could affect the accuracy.

Further information on the work of the Station can be obtained in the Station's Annual Report.

WEEDS

UNIT OF EXPERIMENTAL AGRONOMY

Department of Agriculture, University of Oxford

Honorary Director: G. E. Blackman, M.A., F.R.S.
(Sibthorpean Professor of Rural Economy, University of Oxford)

Assistant Director: E. K. Woodford, O.B.E., M.Sc., Ph.D., D.I.C.

SELECTIVE TOXICITY AND HERBICIDAL ACTION

J. D. Fryer, M.A.

R. J. Chancellor, B.A.

J. G. Elliott, M.A.

K. Holly, B.Sc.(AGRIC.), Ph.D.

C. C. McCready, M.A., D.Phil.

Miss D. J. Osborne, M.Sc., Ph.D.

R. G. Powell, B.A.

NEW CROPS—PARTICULARLY OIL SEED CROPS AND HYBRID MAIZE

E. S. Bunting, B.Sc., Ph.D.

INFORMATION SECTION

L. Kasasian, B.Sc.

The long-term programme of research undertaken by the Unit is divided into two parts. One series of investigations relates to a broad-based study of chemical methods of weed control, ranging from fundamental work on the factors determining selective action to extensive field trials concerned with the development of practical methods of weed eradication. The other part has as its aim the assessment of the environmental and agronomic conditions which

will permit the cultivation of new or unusual crops in Great Britain. On 31st March, 1960, the scientific and experimental staff of the Unit numbered twelve. Four members were subsequently transferred to the new Weed Research Organisation under Dr. E. K. Woodford which, with additional staff, will take over and extend work on the practical application of weed control methods.

CURRENT WORK

For the basic investigations on the nature of herbicidal action the general pattern of research remains the same from year to year though there will be alterations in emphasis. For example, studies on the uptake of phytotoxic compounds are being continued both by members of the Unit and research students within the Department. It has previously been established that the course of uptake of plant growth regulators such as 2,4-dichlorophenoxy-acetic acid (2,4-D) by roots or stem segments is dependent upon the species. While for some species (e.g. oats, wheat, barley and rice) 2,4-D steadily accumulates in the tissues, for other species (e.g. cotton, sunflower, mustard) an initial phase of accumulation is followed by a second phase when the direction of flow is reversed and the compound moves from the tissues back into the solution. It has now been further shown that for substituted phenoxy-acetic acids the pattern of uptake is highly correlated with chemical structure. For some compounds the accumulation takes place in all tissues, while for others whether there is a reversal of flow is dependent on the species.

This type of investigation is being extended to an analysis of the operative factors which determine the rate of penetration of 2,4-D and related compounds into leaves. Under the standardised experimental conditions it has been found that the amount penetrating is dependent on the external concentration, temperature, the age of the leaf, and whether the experiments are conducted in the light or in the dark. There can also be very large differences in the rate of penetration both between species and between the upper and lower surfaces of leaves.

From these basic studies it is already apparent that the selective action of 2,4-D and related compounds can be linked with differences in the patterns of uptake and leaf penetration.

Another facet of the basic programme relates to the factors which control the movement of the herbicides once they have entered the roots or penetrated the leaves. Special attention is being paid to assessing the conditions which allow the maximum movement from the shoot to the root since the effective eradication of perennial weeds with a large underground system is dependent on the extent of the downward movement. At present a study is being made of the conditions which allow the maximum transport of 2,2-dichloropropionic acid from the shoots to the rhizomes of *Agropyron repens* (couch grass).

In connection with the field investigations, mention was made in the previous report of an experimental machine for the incorporation of herbicides in the soil at the same time as the seed is drilled. In an initial series of field trials, principally with sugar beet and maize, promising results have been obtained for the selective suppression of weeds germinating in the row. The successful development of herbicides for the selective eradication of many annual dicotyledonous weeds has re-emphasised the need to kill annual grasses, such as the

two species of wild oats. Since practical considerations demand that these species should be controlled in cereal crops progress has been held up by the lack of compounds with a very high specific selectivity. Current research suggests that there are good prospects that control will be possible in wheat and barley. A considerable variability between experiments has been shown for one compound and this requires further elucidation.

Over the last few years the Unit has collaborated with the Rubber Research Institute of Malaya in a programme of research to increase the yield of rubber in mature trees by localised applications of growth regulators. As a result of earlier work in Malaya it was established that appreciably higher levels of production could be achieved by the application of the butyl esters of 2,4-D or 2,4,5-trichlorophenoxyacetic acids above or below the tapping cut. In consequence, this practice has been widely adopted by rubber growers.

For a further series of experiments a range of new compounds or formulations have been synthesised by the Unit at Oxford for trial in Malaya by the Institute. In selecting the compounds the Unit had two aims in view: to obtain a better understanding of the relationship between chemical structure and the ability to increase latex flow; and to test out some new compounds which it was postulated on *a priori* grounds might have a higher activity. The results of five extensive experiments suggest, that one of the new compounds is superior to either 2,4-D or 2,4,5-T.

In the programme of research on new crops the main investigations have been continued. The high productivity of hybrid maize as a silage crop has been confirmed. It is clear that some of the newer hybrids raised by European breeders are well adapted to conditions in the southern half of England. A further analysis is being made of the influence of density on the maximum level of dry matter production and the ratio of ear to shoot weight at the time of harvesting. The introduction of herbicides which allow of selective weed control and the development of forage harvesters suitable for this crop, are other factors which are leading to an increasing interest in hybrid maize as a silage crop.

In a further appraisal of the opium poppy the breeding programme is being continued with the primary objects of combining a good yield of seed and a higher morphine content of the capsule with earliness and a short "straw." The distribution of the morphine within the plant at various stages of development is being followed.

PESTS AND DISEASES

A.R.C. UNIT OF INSECT PHYSIOLOGY

Department of Zoology, University of Cambridge

Director: Professor V. B. Wigglesworth, C.B.E., M.A., M.D., B.CHIR., F.R.S.

Senior Scientific Staff:

J. W. L. Beament, M.A., SC.D., PH.D.

W. A. L. David, M.A., PH.D.

J. S. Kennedy, D.SC., PH.D.

A. D. Lees, M.A., PH.D.

A. Milne, M.A., D.SC., PH.D., F.R.S.E.

J. E. Treherne, B.A., PH.D.

R. Laughlin, B.A.

The Unit carries out fundamental research on the physiology of insects, particularly in fields which are likely to prove of direct or indirect value in the control of insect pests. On 31st March, 1960, the scientific and experimental staff of the Unit numbered eleven.

Last year's report described the work of the Cambridge section of the Unit on the nature and properties of the insect cuticle. Another part of the work is concerned with the study of insect populations. Researches in this field have been undertaken at Newcastle-upon-Tyne since the Unit was established in 1943.

Detailed studies have been made of the biology and ecology of selected pests: (1) The Sheep Tick (*Ixodes ricinus*), (2) The Garden Chafer (*Phyllopertha horticola*), (3) Leather-jackets (*Tipula paludosa* and *T. oleracea*), (4) The Swede Midge (*Contarinia nasturtii*), and (5) Slugs (*Agriolimax reticulatus*, *Arion circumstriptus* and *A. intermedius*). Such work is generally done by ecologists alone. At Newcastle a physiologist forms a member of the ecological team.

The work has two aims. The first is to meet some of the practical needs of the advisory entomologists by providing knowledge of the biology and ecology of these pests, together with improved methods of field-sampling and laboratory-culture. The second is to further understanding of the spatial distribution and fluctuation of pest populations with the ultimate object of discovering why an organism is a pest only in certain places or in certain years. The following are some points of interest that have been brought to light.

Sheep Tick. This study is complete and published. In the tick population fluctuation is less important economically than spatial distribution of numbers. For the most part, spatial distribution today can be explained adequately in terms of interplay between amount of ground-cover and of host-potential, with cover the master factor. Thus ticks are most numerous where cover is deepest and hosts most plentiful, i.e. on hill grazings. Unfortunately, reduction of cover is uneconomic there. However, hill sheep provide nourishment for 94-99 per cent of all female ticks on their grazings and this finding has been the key to the present fairly adequate control by dipping.

Garden Chafer. This study is now complete. Some details from earlier papers were given in the 1956-57 Report. More recent papers deal with the flight season and its two phases: Phase 1, the swarming of the beetles over the grass sward, followed by Phase 2, the swarming on the surrounding bracken hedges and trees. The flight season is important ecologically because certain aspects of behaviour at that time (male swarming, female reactions to male clasping and to delay of clasping in Phase 1; "bee-line" flying of some females in Phase 2) profoundly affect spatial and temporal distribution of numbers.

Swede Midge. This study is nearing completion. Population levels fluctuate mainly through the action of soil moisture (pF) and temperature on the final larval stadium. Parasites appear to exert little influence, their numbers often diminishing at a time when midge population is on the increase.

Leather-jackets. This study is proceeding. Progress in the field has been somewhat hindered by several years of very low populations. Two species of the same genus, with apparently similar habits and habitats, are being investigated simultaneously. Comparison of their biological-ecological regimens may clarify the reasons why one is and the other is not a pest in the North of England. A similar approach is being made in the recently-commenced Slug investigations..

Contributions to General Theory and Practice. These include papers on the natural control of insect populations, on statistical aspects of area-sampling and on an original method of extracting organisms from turf (the so-called "hot-water-process").

A.R.C. VIRUS RESEARCH UNIT

Huntingdon Road, Cambridge

Director: R. Markham, M.A., PH.D., F.R.S.

Senior Scientific Staff:

K. M. Smith, C.B.E., D.S.C., F.R.S.
J. H. Hitchborn, B.SC., PH.D.

M. W. Rees
D. B. Dunn, M.A., PH.D.

The work of the Unit is concerned mainly with the investigation of viruses of plants and insects, and the diseases which they cause. In addition, because of their relation to virus diseases, the general properties of nucleic acids and nucleoproteins from various sources are also being investigated.

At the end of 1959 Dr. Kenneth Smith relinquished the Directorship on reaching the retiring age, and was succeeded by Dr. Markham. Dr. Smith, however, is continuing for the time being his work with the Unit.

On 31st March, 1960, the scientific and experimental staff of the Unit numbered nine.

CURRENT WORK

The chemical composition of a number of strains of tobacco mosaic virus is being investigated. Of particular interest is the composition of a number

of such viruses which infect leguminous plants, for example, the Sann hemp virus and the Cowpea virus. These all seem to have a characteristic peptide structure which is markedly different from that of the ordinary tobacco mosaic viruses found in solanaceous plants. This work is also of interest because there is an indication that these various strains may have originated by selection of mutants occurring in ordinary tobacco mosaic type viruses, and so may shed light on the origin of virus variants.

The state in which viruses exist in untreated plant saps is being investigated by means of the ultracentrifuge and it has been found that certain of the treatments quite commonly used during the purification process have marked effects on the physical properties of the isolated viruses. Some of these effects appear to be irreversible. Similar minor changes may account for the loss of infectivity frequently found in purified virus preparations. In the course of this work a rapid and accurate method for calculating sedimentation co-efficients has been devised, and it is proposed to make the procedure easily available for all users of ultracentrifuges.

The spherical or, rather, icosahedral, small plant viruses are also being investigated and the structure of some of these has been demonstrated by electron-microscopical observation. Attempts are being made to correlate these findings with the other physical information available about these viruses, and also with the analytical data which have been obtained concerning their protein composition.

The state in which the nucleic acid is held inside "spherical" viruses is also being studied. It has proved possible to isolate the nucleic acid from one of these viruses in a condition in which it is nearly completely undegraded and it would appear that the nucleic acid is released as a single piece which is probably cross-linked by basic substances, some of which are polyamine in nature.

Studies of the chemical structure of nucleic acids have been largely concerned with the nature and distribution of the methylated bases and of pseudouridine in the various fractions of ribonucleic acid from micro-organisms and plant and mammalian tissues. The interest in this work is in the implication of some of these nucleic acid fractions in the activation of amino acids.

Studies of the *Tipula* iridescent virus are continuing. This virus is unique among insect viruses in having a very wide host range which includes several orders of insects. There is an indication that the physical structure of the virus is modified according to the host on which the virus is grown. When grown on certain hosts the virus preparation appears to be considerably less uniform than that obtained by growing it on its original host, and the surface structure as seen under the electron microscope also appears to be rather different. Attempts are being made to follow the "life-cycle" of this virus by means of radioactive tracer labelling.

HILL FARMING

HILL FARMING RESEARCH ORGANISATION

48, Palmerston Place, Edinburgh, 12

Director: A. R. Wannop, O.B.E., B.SC.(AGR.), B.ENG., F.R.S.E.

ANIMAL STUDIES

Head of Department: J. F. Robinson,
B.SC.(AGR.)

J. M. Doney, B.SC., PH.D.
J. N. Peart, B.SC.(AGR.), M.SC.

BOTANICAL STUDIES

Head of Department: R. F. Hunter,
B.SC.(AGR.), PH.D.

R. Hughes, B.SC.(AGR.), M.SC.
J. King, B.SC.(AGR.), PH.D.
I. A. Nicholson, B.SC.(AGR.), M.SC.

Secretary: R. S. Boyd

The Organisation exists to investigate methods of improving the agricultural output of hill land and the problems that arise in doing so.

At 31st March, 1960, the scientific and experimental staff of the Organisation numbered twenty-four.

CURRENT WORK

Animal Studies. In 1959 fleece studies were introduced into the research programme. Seasonal changes in wool production have been found to be large, absolute production being at a peak in August–September, afterwards declining, slowly at first, but rapidly in the January–April period. Data on the shedding cycle, the change in fibre structure and the relative production of different fibre types have been collected and are being analysed. Some preliminary information on the effects of pregnancy and lactation on wool growth has also been obtained, and differences in wool production and fleece structure between body regions have been investigated.

Supplementary feeding of ewes in the later stages of pregnancy continues to form an important part of the Organisation's investigations into the problems of the "hungry gap." A technique for the individual feeding of supplements on the hill is now used and enables more critical studies to be made. In winter 1959–60, the responses of two groups of ewes receiving supplements containing 6.5 per cent and 14.0 per cent Digestible Crude Protein respectively, but having the same energy value, were very similar. Unfortunately, it is not yet possible under hill conditions to assess the protein content of the natural herbage eaten, so that the total protein intake of the two groups is unknown. A supplement containing 14 per cent D.C.P. derived from animal and vegetable protein gave no better performance than one with vegetable protein only. Five years' trials of supplementary feeding on the hill emphasise the importance of adequate nutrition in summer and autumn so that ewes can recuperate after pregnancy and lactation and build up adequate reserves to meet the stresses of the hungry gap period.

A review of neo-natal lamb losses in the Organisation's flocks in recent years indicates a complexity of predisposing causes, many aspects of which

are only indirectly connected with the nutritional status of the ewes. Maximum percentage losses occur amongst the smallest lambs, but losses can also be high amongst the heaviest lambs, apparently due to difficult and delayed parturition. Variations in this respect occur between breeds and male lambs, being heavier, suffer greater loss in the heavier weights. Environment and age of dam also affect the chances of survival even among lambs of the same weight.

During each of three winters, groups of Cheviot ewe hoggets were reared on high, medium and low planes of nutrition. All groups had the same management after reaching twelve months of age and their performances in the breeding flock are now being recorded. At predetermined intervals representatives of each group were slaughtered, and dissections and skeletal measurements made. The oldest group is now $4\frac{1}{2}$ years of age and has reared three crops of lambs. Though the low plane group reared fewer lambs in their first breeding year, their production since is as satisfactory as that of the medium and high plane groups and in skeletal development they appear now to have reached the stage that the higher plane groups attained at least twelve months earlier.

Shelter, whether geomorphic or added, is of importance to hill flocks, especially during late pregnancy, at parturition and when ewes are newly shorn. The inclination of a group of Blackface ewes to seek shelter is being closely observed on an area of varied topography which also provides an admixture of heather and grass species. The voluntary movements of the sheep in response to changes primarily in wind speed and direction and also in temperature and humidity are being recorded.

Work has continued on mineral metabolism and dentition, strain trials, selection for milk yield, the effects of hormones on lamb growth and the controlled grazing of hill pastures.

Botanical Studies. In studying the effect of burning on the subsequent growth of the vegetation, the increase in flowering shown by *Molinia caerulea* has been investigated. Early in this work it became clear that this is not caused by a higher nutritional level as no flowering response was occasioned by manurial dressings. The cause has now been identified as the physical removal of the litter layer which, whether effected by raking or by burning, leads to higher temperatures both in the *Molinia* tussock and in the soil, and to increased flowering.

An important question connected with the common practice of burning in the management of hill pasture is how far it leads to loss of mineral nutrients. When the material burnt is *Molinia* litter, which contains only very small amounts of minerals, the loss is thought to be inappreciable. The loss when heather is burnt is not yet known, but is being studied.

Sheep behaviour, under conditions of free range grazing, is of major interest and has been studied since 1956. The salient features have now been identified. The sheep show a marked preference among the different hill pasture sward types and this preference varies seasonally. The concentration of grazing is such that 50 per cent of the pasture area may afford 80 per cent of the utilised grazing. In their grazing range, they show territorially a strong family association and individual sheep adhere to the same territories as their dams. These aspects of behaviour are under consideration in relation to improvement proposals.

Some experience has now been gained on the value of herbicides as an aid to surface sowing—the technique sometime called “chemical ploughing.” This appears to be a promising method, more so, however, in areas of high rainfall than in the south-east of Scotland, where the lower rainfall and the thick turf mat may lead to a poor establishment after surface sowing, as was specially marked in the dry autumn of 1959 and spring of 1960. The possibility of drilling the seed into the dead mat is now being studied though this may involve the development of special implements.

A herbicide for killing bracken has also been under study and attention has been given to methods of treating the sward (including surface sowing of a seeds mixture) after the bracken has been weakened or killed.

In the current studies of the drainage of peat, the first full year's records of rainfall, evapotranspiration and run-off are being collated. Run-off characteristics show considerable variation not only according to the nature of the rainfall but related also to the condition of the peat surface.

A study of the natural population of heather (*Calluna vulgaris*) has shown this species to be polymorphic, ranging from prostrate dense to erect open forms between which differences in growth rate and flowering date also occur. The prostrate dense form is more prevalent in populations from high altitude and northern island sites, and is perhaps an ecotype selected by the shorter growing season and greater exposure of these environments.

The Organisation has completed a three-year study on the agronomic value of a number of grass varieties. They were single-sown with white clover, and surface seeded over a wide range of upland soil/vegetation types. The high value for hill improvement of red fescue and pasture strains of rye-grass has been shown, as has the high potential under certain environmental conditions of persistent varieties of cocksfoot and timothy. Certain attributes of meadow and tall fescue need closer examination since a higher-than-expected level of performance of these species was seen over a wide range. Further studies of smooth-stalked meadow grass will be made on account of its high response to nitrogen.

ANIMAL BREEDING

A.R.C. ANIMAL BREEDING RESEARCH ORGANISATION

Headquarters: Glenbourne, South Oswald Road, Edinburgh, 9

Director: H. P. Donald, D.SC., PH.D., F.R.S.E.

Senior Scientific Staff:

N. Bateman, B.SC., PH.D.	J. W. B. King, M.A., PH.D.
H. B. Carter, B.V.SC.	A. F. Purser, B.SC., A.R.C.S.
A. G. Dickinson, B.SC., PH.D.	St. C. S. Taylor, M.A., PH.D.
J. G. Hall, PH.D., M.R.C.V.S.	G. Wiener, B.SC., PH.D.
J. L. Hancock, M.V.SC., PH.D., M.R.C.V.S.	G. B. Young, PH.D., M.R.C.V.S.
A. Jamieson, B.SC., PH.D.	

Livestock Officers:

Pigs: G. R. H. Bishop, M.SC., N.D.A., N.D.D. *Sheep:* J. L. Read, B.SC.
Cattle: D. Gibson, B.SC., M.S., S.D.D.H.

Secretary-Treasurer: F. H. James

The purpose of the Organisation is to acquire knowledge essential to the development by breeding of livestock of improved performance under both present and future husbandry conditions.

At 31st March, 1960, the scientific and experimental staff numbered fifty-one.

CURRENT WORK

Dairy Cattle

Twins. Everyone knows that, even with the same breed, some herds have better average yields than others, but it is not easy to discover why any two herds differ. Yet it is important to learn why—if the right kind of advice is to be given to farmers having lower-yielding herds. Twins were used in a recent experiment to study this problem. Whilst identical twins might have been more efficient, the cheaper fraternal twins were preferred. Each of 65 female pairs was split, one calf being placed in a high-yielding herd and the other in a low-yielding herd. The “high” farm heifers grew faster than those on “low” farms for the first 18 months or so: at 3½ years old they still maintained some of their size advantage over their co-twins. Their conformations also differed—a point of some significance when progenies from sires at Artificial Insemination centres are to be compared.

Analysis of the milk yields suggests that, on average, about a quarter of the difference between the high-yielding and the low-yielding herds is genetic in origin, but this estimate has a large statistical error and is probably too high. Records were kept of management and feeding in all the herds where twins were placed but it was not possible to pin-point any single factor of management or environment as the cause of the difference in herd yields.

Much is to be said for experiments of this sort which link farms and laboratory, but the difficulties are discouraging and may be judged by the fact that only 24 pairs of twins survived to complete a first lactation.

Crossbreeding. Interim results from the cyclical crossing experiment (mentioned in an earlier report) with Friesian, Ayrshire and Jersey cattle have shown so far no striking departure from the rule that crossbreds are intermediate between the parents in performance. Not all aspects of performance have yet been studied, and consequently this statement applies only to those which have, namely, body dimensions, butterfat percentage, and liveweight at 18 months of age. There is evidence that the crossbreds are not exactly half-way between the parental averages. Indeed, this would not be expected; but for practical purposes they can be described thus. The point is worth making because an assessment of hybrid vigour depends on it.

No one will be surprised to learn that first crosses between pure breeds are as uniform as the parents. The offspring of crossbred mothers, being three-breed crosses, might however have been expected to show more variation than either. But they do not. One of the principal objections to crossbreeding dairy cattle has already disappeared for artificial insemination overcomes the difficulty of securing whatever breed of sire is desired. Now the fear of excessive variation seems likely to prove groundless. Whether there is any productive advantage to be gained from crossbreeding is a question not yet to be answered. It revolves round milk yield, conception rates, and health, and for these characters more data are needed than for those mentioned above.

Blood Groups. Blood groups are much in the scientific news. In man, many clear cut differences in blood characters have been found over and above that well-known diversity exploited in the technique of blood transfusion. The same position is rapidly arising in livestock. Consequently, much work is going on to see whether there is any connection between blood groups and milk production or egg-laying or fecundity. The Organisation is deeply interested in these matters.

One problem is to devise methods of identifying the blood groups that are internationally acceptable. Laboratory workers all over the world want to understand precisely what their colleagues are saying and to repeat their work. To this end, some international reference system is necessary.

Techniques and reagents have been developed in Britain for characterising 33 factors in the blood of cattle. The reagents have been compared with those produced by 12 European laboratories and claimed to be replicates of those originally named at Wisconsin, U.S.A. Only 18 of the British reagents were clearly identified. These details are mentioned to show why it is the data from different laboratories on individual animals cannot yet be regarded as interchangeable. For this reason, the produce of exported animals or semen cannot be tested except by sending all bloods to one laboratory.

The preparation, isolation and identification of reagents has continued during the year and they have been used to test the accuracy of about 200 parentage records.

Sheep

An experiment was started a few years ago at the Organisation's upland farm of Blythbank to study the effects of crossbreeding and of inbreeding

in sheep, with particular regard to body size, growth rate, maternal performance and fleece characteristics.

The foundation stock was purchased from numerous sources as ewe lambs—72 of each of the Blackface, Cheviot and Welsh Mountain breeds, and a smaller number of Lincoln and Southdown. These five breeds, together with the Tasmanian Merinos used in the crossing phase of the experiment, provide a wide range of variation in the characteristics chosen for study.

During the first winter, interest centred on the rare opportunity to compare five breeds run as a single flock. The big Lincolns lost heavily in weight, whilst the small Welsh, as a group, gained almost unchecked. The Southdowns were slightly lighter than the Cheviots on arrival, but overtook the latter almost at once and stayed a little ahead until the age of 15 months. Blackfaces at first grew faster than the Cheviots but both breeds reached the same weight (145 lb. on average) at $4\frac{1}{2}$ years old. Evidence from the first crop of reciprocal crosses suggests that the initially greater rate of gain of the Blackface, may have been due, not to a greater potential for growth, relative to the Cheviot, but to better mothers. The Welsh ewes reached a mature weight of 103 lb.; this is 50 per cent greater than average on the Organisation's hill farm in Wales.

Growth curves based on body measurements showed that the length of cannon, tibia and head continued to grow more or less evenly during the first year at Blythbank. Body length increased more rapidly in spring and summer than in autumn and winter, but chest depth, hook width and shoulder width, like body weight, diminished during winter.

The prolificacy of the three hill breeds run as a grassland flock has been very high: for every Blackface ewe tupped there were 5.4 lambs born in the first three crops, 5.0 for the Cheviots, and 4.4 for the Welsh. Blackface ewes also weaned the heaviest lambs, their superiority being more marked with twins than with singles.

Pigs

Selection for Carcass Quality. The inbred lines of Large White pigs at present available were bred without consideration for carcass quality. Crosses of these lines in various combinations show that the resulting carcasses tend to be rather short and fat. Analysis of past records shows a tendency for the shorter and fatter lines to survive the inbreeding process better. Attention has therefore been paid to improving carcass quality during the inbreeding phase of the programme. One way of doing this is to X-ray young pigs at one week old to obtain counts of vertebrae. This information is combined with measurements of skeletal length into an index from which eventual carcass length can be estimated. When young pigs are being selected for continuing the inbreeding, those promising to have the longest bodies can be preferred. Another way, needing a suitable method of restraint, is to measure the thickness of the outer layer of fat on an animal intended for breeding. This can be done with good accuracy at 170 lb. liveweight by an ultrasonic machine of the type used as a flaw detector. These two methods are being tried out in the development of new inbred lines.

Artificial Insemination. Artificial insemination of pigs is hindered by the apparent need for large quantities of semen. In two recent experiments good results have been achieved with relatively small sperm doses by inseminating

into the uterus. Possibly, therefore, the need for large doses is due more to technical difficulties of insemination than to any special physiological feature of the pig.

Most of the experimental work in the Organisation is done on surplus sows which are slaughtered within 3-4 days of insemination and success is judged from the proportion of sows slaughtered which yield fertilised eggs and from the proportion of eggs which are fertilised. These figures may be regarded as estimates of pregnancy rate and of litter size. But estimates of this sort may be effected by two factors. Firstly, the precision of estimates based on the number of fertilised eggs depends on how well an observer can distinguish between fertilised and unfertilised eggs. Secondly, if the development and survival of fertilised eggs are affected, as has been suggested, by factors such as the volume of semen inseminated, then the percentage of ova fertilised will give an inaccurate estimate of the number of pigs likely to be born, even when allowance is made for the loss of embryos which occurs normally between fertilisation and farrowing. These questions are being studied to ensure that experimental results will be applicable to insemination in the field.

A.R.C. UNIT OF REPRODUCTIVE PHYSIOLOGY AND BIOCHEMISTRY

**Molteno Institute of Biology and Parasitology and School of
Veterinary Medicine, University of Cambridge**

Director: T. R. R. Mann, M.D., SC.D., PH.D., F.R.S.

Deputy Director: L. E. A. Rowson, O.B.E., M.R.C.V.S. (Part-time)

Senior Scientific Staff:

C. E. Adams, B.Sc., PH.D.
J. C. Bournsnel, B.Sc., PH.D., F.R.I.C., A.R.C.S.
E. F. Hartree, M.A., B.Sc., PH.D.

E. J. C. Polge, B.Sc.(AGRIC.), PH.D.
R. V. Short, PH.D., M.R.C.V.S.

On 31st March, 1960, the scientific and experimental staff of the Unit numbered ten. The two major events of the year, in the activities of the Unit, have been the British Council Course on "Recent Advances in the Study of Animal Reproduction," and a Colloquium, held jointly with the members of the staff of the Station de Recherches des Physiologie Animale, Jouy-en-Josas, on "Problems in Animal Reproduction."

CURRENT RESEARCH

Problems in the Male. Further progress was made in the physiology and biochemistry of semen. The observation that in the absence of fructose mammalian spermatozoa can use their intracellular plasmalogen lipid as a source of metabolic energy, has been confirmed and extended. It was shown that free fatty acids are liberated during incubation of spermatozoa; the oxidation of these acids by oxygen enables the spermatozoa to remain motile. Lysoplasmalogen, the compound derived from plasmalogen by the removal of fatty acids, has been prepared in crystalline form.

Experiments have been continued on freezing and freeze-drying of spermatozoa. A biochemical method was developed which makes it possible to assess the activity and survival of spermatozoa in mixtures of semen with non-transparent storage media such as milk diluents. It was also shown that when bull spermatozoa are stored in the presence of a glycine-containing egg-yolk diluent, their heads undergo definite shrinkage.

In the field of endocrinological studies, mainly relating to the function of gonadotrophins and testicular androgens in the male organisms, one notable advance has been the demonstration by chemical methods that the time at which testosterone appears in the tests of young bull-calves corresponds closely to the onset of fructose and citric acid secretion in the seminal vesicles. Furthermore, it was established that in animals approaching sexual maturity the appearance of testosterone in the testes is preceded by the formation of a chemically related, but androgenically much less active steroid, namely androstenedione.

Problems in the Female. Further progress was made in studies on the mechanism underlying the processes of fertilisation and passage of ovum through the oviducts, the physiological and biochemical properties of the early embryo (blastocyst), and the problems of foetal mortality. A method has been developed, based on the autoradiographic detection of "artificial ova" marked with a radioactive isotope, whereby one can determine accurately the rate of movement of fertilised ova along the different portions of the oviducts into the uterus. This method, originally based on experiments with rabbits, is now being applied to the sheep, with particular reference to studies on the effects of various agents on the movement of ova in the oviducts.

As a result of an extensive investigation of the action upon the blastocyst of various agents administered parenterally to pregnant rabbits, it was found that some of the embryotoxic substances specifically act upon the embryonic disc, whereas others affect equally the germ disc and the area of the trophoblast. The chemical composition of the blastocyst fluid, especially its content of glucose, lactic acid and bicarbonate, was studied in embryos of normal rabbits and in animals which had been pre-treated with embryotoxic materials. Endocrinological studies in the female were extended to include investigations on the occurrence and mode of action of oestrogens and progesterone. The analysis of normal follicular fluid from mares revealed the presence of no fewer than nine steroids, including three not previously recorded in nature. Progesterone determinations in pregnant women have shown that women with twins or triplets tend to have much higher blood progesterone levels than those with a single foetus; this method may help to diagnose multiple pregnancy at an early stage.

A.R.C. UNIT OF ANIMAL GENETICS
Institute of Animal Genetics, University of Edinburgh

Honorary Director: Professor C. H. Waddington, C.B.E., M.A., SC.D.,
D.ES SC., F.R.S., F.R.S.E.

Deputy Director: D. S. Falconer, B.Sc., PH.D.

ANIMAL BREEDING
A. Robertson, B.A., D.SC.
I. L. Mason, B.A.

DEVELOPMENTAL PHYSIOLOGY
C. H. Waddington, C.B.E., M.A., SC.D.,
D. ES SC., F.R.S., F.R.S.E.

MOUSE GENETICS
D. S. Falconer, B.Sc., PH.D.

**MAMMALIAN GAMETES AND
EMBRYOS**
R. A. Beatty, M.A., PH.D.
Miss A. McLaren, M.A., D.PHIL.

DROSOPHILA GENETICS
E. C. R. Reeve, B.A., PH.D.
F. W. Robertson, D.SC., PH.D.

On 31st March, 1960, the scientific and experimental staff numbered sixteen.

The aims of the Unit are: (a) to carry out operation research on the live-stock industry; and (b) to study those aspects of genetics and developmental physiology which seem likely to be particularly relevant to our fundamental understanding of animal breeding problems.

CURRENT WORK

Animal Breeding. A year's tour of several tropical and sub-tropical areas provided material for completing (with J. P. Maule) "The indigenous livestock of Eastern and Southern Africa" and for reports and lectures on the problems of tropical animal breeding.

Progeny testing of Friesian bulls for beef production has now been completed on 43 bulls and a further 19 are still on test.

The investigation of the association of blood group factors and production characteristics in dairy cattle (in collaboration with Dr. Neimann-Sorensen in Denmark) has now been completed. Although some definite associations of blood-group alleles and fat percentage have been found, it seems that a knowledge of blood groups is not likely to be an important help in dairy cattle selection.

From the analysis of poult production data in turkeys, a programme of full-sib family selection based on egg production in the first six weeks of lay seems promising and is being tried out in practice.

Work using *Drosophila* has included the investigation of selection indices, assortative mating and the effectiveness of replication within selection programmes to utilise variation between replicates in response to selection.

In a selection programme, the effective population size is often below the expected value because members of the better families are more likely to be selected. This has been analysed theoretically.

Using an electronic computer, a general study has been made of the effectiveness of selection for heterozygotes in retarding the approach to homozygosis in small populations.

Mammalian Gametes and Embryos. The study of genetic effects on gametes continues. The dimensions of the head and midpiece of spermatozoa, and certain measures of viability, vary characteristically between inbred strains of mice, and between strains of rabbits. The spermatozoa of hybrid mice bred from the crossing of inbred strains display heterosis. In some instances the heterosis is of an advantageous nature and can be properly be termed hybrid vigour. The general pattern of variation in spermatozoan dimensions is unusual in that genetic variation is paramount and there is little evidence of environmental effects. Age of the male has little effect on the dimensions of mouse and rabbit spermatozoa. From new data and from a re-examination of the literature, it appears that the spermatozoa of a mammalian species do not fall into two size classes representing X- and Y-bearing spermatozoa; in this work, statistical methods for the study of "bimodality" in distributions have been elaborated. Genetic transformation has been attempted by incubating rabbit spermatozoa with DNA from rabbits of a different genotype, followed by artificial insemination and examination of the offspring for genetic deviants. Study of the genetics of *Drosophila* spermatozoa has begun.

The following aspects of male fertility have been studied in rabbits. Spermatozoan characteristics of value in predicting male fertility are — length of the head; incidence of eosinophile spermatozoa; and, in particular, the incidence of spermatozoa with abnormal acrosomal caps. Heterospermic insemination with a mixture of equal numbers of spermatozoa from two males, followed by a count of the numbers of offspring sired by each male, seems to be an efficient way of comparing the fertility of the males, and could help in the selection of males for high fertility. There is suggestive evidence of increased fertility attributable to heterospermic insemination *per se*. In one experiment, a male with sterile semen fathered some offspring after addition of semen from another male. The so-called "enhancement effect" has been confirmed in a new experiment with heterospermic insemination; the difference in birth weight between genetically large and small offspring born in the same litter is greater than when they are born in litters all of one type; this is attributed to competition *in utero*. It has been found that the fertility of a given male, as well as the dimensions and other characteristics of his spermatozoa, remain remarkably constant for as long as twelve months.

Foetal growth in polytocus mammals is greatly influenced by the number of young in the litter. The relative influence upon embryo weight of other embryos in the same horn and the opposite horn of the uterus, and of embryos surviving to term and dying at different stages of gestation, has been analysed in mice. Data on birth weights in both mice and pigs have also been examined in order to throw light on the genesis of runts.

The extent of early embryonic loss is often inferred from a comparison between the number of corpora lutea and the number of implants. Counts of corpora lutea, recently ovulated eggs, and implants suggest, however, that at any rate in mice in which superovulation has been induced, the number of corpora lutea may greatly exceed the number of eggs shed. In such cases, estimates of pre-implantation loss based on corpora lutea counts will be spuriously high.

Mouse Genetics. The mice were moved in October into a new animal house where conditions are greatly improved. The experimental selection for high

and low litter size has been concluded. Progress ceased after about 20 generations and the final levels reached were 9.2 mice per litter in the high line and 6.0 in the low, while the control line maintained an average of 7.6 throughout. Dissections of females showed that the increased fertility of the high line was due to a much increased ovulation rate, which was partly offset by an increased prenatal loss. The reduced fertility of the low line, however, was not due to a change in ovulation rate but to a much increased prenatal loss. About 30 per cent of embryos died soon after implantation. Their death was attributable to the mother and was not a function of the embryo's genotype.

A study has been completed on reciprocal recurrent selection applied to two strains previously selected to their limits for body size. No detectable progress was made. The two strains were, however, very poor in reproductive performance and it was not possible to apply more than a very mild selection. An interesting result was that the fertility of the two lines declined even further after selection for crossing performance had been applied. As an alternative method of improvement straightforward selection was applied to the cross-bred population derived from the same two lines. This yielded good progress, and as a method of improvement was clearly superior to reciprocal recurrent selection.

The following new work has been started:

- (1) Crosses in all combinations have been made between the Unit's four large selected lines and between their three small lines. The crosses are being analysed for combining ability, maternal effects and any other points of interest. New selected lines are being started from the cross-bred populations. The aim for one line is to apply selection primarily for productivity in order to try to counteract the loss of productivity that has always previously accompanied selection for body size.
- (2) An exploratory study is being made of the body temperature of mice, with the object of finding out if this would be a suitable character for the study of certain aspects of quantitative genetics, particularly the genetic control of physiological homeostasis.
- (3) A new random-bred stock has been set up, which it is hoped will become the standard material for future experiments. A mating system has been devised for it which will provide the basic data for computing the genetic parameters of any quantitative character on which measurements are made.
- (4) A study (supported by a grant from the Medical Research Council) of the inheritance of susceptibility to induced pulmonary tumours is being made by Miss Joyce Bloom. The number of tumours is taken as a measure of susceptibility. The heritability of susceptibility is being estimated by offspring-parent regression, and the degree of genetic determination by comparison of the variances of F_1 's and the random-bred stock.

Professor G. E. McClearn, on a visit from Berkeley, California, has made a study of the heritability and degree of genetic determination of spontaneous locomotory activity.

Drosophila Genetics. Work is continuing on the quantitative relation between X-ray dosage and the level of new genetic variations affecting various

quantitative characters. Preliminary results suggest that the amount of new variation created by a given dosage is relatively greater for biometrical characters such as body size, than for pattern characters such as the number of bristles in a particular group.

An attempt is being made to measure the amount and distribution of genetic activity affecting various biometrical characters, in limited regions of particular chromosomes.

Inter-relations between genetic behaviour, environment and development, are being analysed in terms of growth rate and the capacity for regulating final size, with the aid of chemically defined aseptic media and strains created by different kinds of selection or inbreeding. Also the association between selection for either small body size or small cell size and additive versus non-additive genetic behaviour is being studied with reference to the origin of inbreeding decline generally.

An attempt is being made to investigate the effect, on the genetic structure of a normally deleterious quantitative character (small body size), of simultaneously selecting both for it and for competitive fitness.

Developmental Physiology. Studies have continued on the ultra structure of differentiating tissues, particularly of the *Drosophila* eye and the urodele notochord. Further evidence has been obtained of the prevalence, during differentiation, of signs of activity of the nuclear envelope and the appearance of ergastoplasmic structures. Both these structural changes are of specifically characteristic types in different kinds of cells.

The turn-over of ribonucleotides (including ribonucleic acid) and proteins in differentiated regions of the chromosomes, and in the nucleolus and cytoplasm, is being studied with high-resolution autoradiography in differently organised nuclei, with a view to establishing relationships corresponding with the supply of genetic information from the nucleus.

ANIMAL DISEASES

A.R.C. FIELD STATION

Compton, Newbury, Berks.

Director: W. S. Gordon, C.B.E., PH.D., M.R.C.V.S., F.R.S.E.

Deputy Director: H. H. Holman, D.S.C., PH.D., F.R.C.V.S.

BACTERIOLOGY

Head of Department: S. J. Edwards,
D.S.C., F.R.C.V.S.

A. McDiarmid, D.S.C., PH.D.,
M.R.C.V.S., F.R.S.E.

J. D. Rankin, PH.D., M.R.C.V.S.

R. L. Chandler, B.SC., PH.D., F.R.C.V.S.

J. M. Payne, B.SC., PH.D., M.R.C.V.S.

PATHOLOGY

Head of Department: I. H. Pattison,
B.SC., M.R.C.V.S.

W. J. Hadlow, D.V.M. (Seconded from
U.S. Department of Agriculture)

C. D. Bracewell, B.SC., B.V.SC., M.R.C.V.S.

A. Mackenzie, M.R.C.V.S.

J. B. Derbyshire, B.SC., PH.D., M.R.C.V.S.

RADIOBIOLOGY

Head of Department: R. J. Garner,
M.A., M.V.SC., F.R.C.V.S., A.R.I.C.

B. F. Sansom, M.A., D.PHIL.

ANIMAL ECOLOGY

Head of Department: A. Brownlee,
B.SC., M.R.C.V.S.

FARMS

Manager: E. V. Knight,
O.B.E., B.SC., N.D.A.

ISOLATION COMPOUND

Manager: J. Elliot, M.A.(AGRIC.)

Secretary: F. R. Meakins

The Council's Field Station at Compton has the function of studying certain diseases of farm animals. It is an estate of 2,000 acres which is farmed intensively to produce feeding stuffs and animals of known health history so that a flow of suitable cattle, sheep, pigs, goats and small laboratory animals from the Station's normal breeding herds can be provided for experiments.

At 31st March, 1960, the scientific and experimental staff of the Station numbered twenty-six.

CURRENT WORK

Contagious Bovine Abortion. Previous work had shown that experimental infection produced a milder, less progressive disease in non-pregnant cows than in pregnant animals. The hypothesis that the more severe disease in pregnant cows might be due to the presence of progesterone was examined but it was found that the daily administration of progesterone to non-pregnant cows did not increase the severity of the disease.

To discover if the S19 vaccine could produce local immunity, intra-uterine injections were made into rats. After challenge by a test dose given intra-peritoneally it was found that the degree of protection was similar to that produced by intra-muscular injection. By either method the immunity was general, and not local in character and neither gave protection to rats infected directly into the lumen of the uterus.

The search continues for a non-irritant and effective vaccine that will not stimulate the production of agglutinins. Accordingly, in collaboration with the Glaxo Laboratories, various adjuvants combined with inactivated *Brucella abortus* (strain 45/20) have been tested but tests have been unacceptable because of the local reaction they produced in cattle. However, one adjuvant, (labelled A₂) has been found to produce only a mild local reaction in cattle yet it stimulates a good immunity in mice and guinea pigs, when combined with inactivated 45/20. Injection produces no systemic effect and no fall in milk production is observed. To assess the immunity produced in cows, 140 cattle are now under experiment, and groups receiving one, two and three doses of vaccine prior to service will be compared with a group receiving S19 vaccine (living) and another that will be left unprotected. All groups will be challenged midway through pregnancy.

The Oxford technical group has continued and extended its survey work based on Compton and over 600 farms in the area have now been screened for brucellosis. A further survey in the Isle of Wight has been completed with the collaboration of the public health authorities and the incidence of the disease on the island determined. Individual, as well as herd infection rates, have been studied in both surveys. Frequently, a close correlation has been found to exist between the detection of infected farms and the occurrence of human cases in the area. A survey of 9,000 "normal" human sera in the vicinity of Oxford has shown that about 1.0 per cent contain *Br. abortus* agglutinins, but no recoveries of the organism have been made from 300 pairs of human tonsils obtained from the Radcliffe Infirmary. A bacteriological examination of placental material from several women with positive blood sero-agglutination tests has also failed to reveal the presence of the organism.

Mastitis. Milk samples from the three dairy herds at Compton have been examined for the presence of pathogenic organisms and treatment of clinical cases supervised. There has been a rise in the incidence of staphylococcal mastitis, mainly in cows soon after calving. In one herd, regular bi-monthly tests have been carried out in order to trace the course of infection due to a penicillin resistant staphylococcus which first appeared in 1958. At present, the incidence of infection due to a sensitive 42D phage type staphylococcus is equal to that due to the resistant 29/52 type.

An experiment on the prophylaxis of *Corynebacterium pyogenes* mastitis is being continued in one herd.

Studies in immunity to staphylococcal mastitis are continuing. It was mentioned last year that a vaccine prepared from *Staphylococcus aureus* strain 201, which produced antitoxic immunity, failed to protect against certain other strains of staphylococci. In further experiments an adjuvant cell toxoid prepared from one such strain (BB) was used to vaccinate goats which were challenged by the homologous organism. This vaccine conferred no greater protection than that conferred by a vaccine prepared in the same way from strain 201 indicating that strain BB is able to produce mastitis in goats in which there is a high level of immunity to the homologous alpha toxin. In an attempt to determine whether an infection with strain BB staphylococci in goats would produce immunity, this strain was inoculated into the teat canal of one half of the udder in a series of gradually increasing doses over a period of ten days. This infection produced mild mastitis only, and five days after the last of

these doses, the goats resisted a massive challenge infection with strain BB inoculated into the same side of the udder, but one week later challenge of the opposite side of the udder with the same strain produced severe mastitis. Thus, the half of the udder previously infected with strain BB showed an increased resistance to this strain, but since this resistance was not shown by the other half, there appeared to be local rather than general immunity to strain BB. Skin abscesses were produced in goats by inoculating a culture of strain BB subcutaneously, and the animals were subjected to mammary challenge with the same strain two weeks later. Three out of four goats so treated resisted challenge. This was the first indication that generalised immunity to strain BB may be produced.

Studies have been carried out in conjunction with the Microbiological Unit of Glaxo Laboratories, where staphylococcal alpha lysin, coagulase and leucocidin have been prepared. A mixture of these antigens has been tested in goats for immunising power against strains 201 and BB, and compared in this respect with adjuvant cell-toxoid. The mixture of alpha lysin, coagulase and leucocidin has been shown to protect goats against strain 201 as efficiently as adjuvant cell-toxoid, and to confer a greater level of protection than adjuvant cell-toxoid against mammary challenge with strain BB in goats. In the most recent experiment, four out of six goats vaccinated with alpha lysin, coagulase and leucocidin resisted mammary challenge with strain BB. This is the first instance of immunity to strain BB being produced by means of a non-living vaccine.

Johne's disease. The long-term experiments relating to the basic question of the infection of cattle with *Mycobacterium johnei* are continuing. The other experiments on the pathogenesis of the organism for calves, mentioned in last year's report, have been completed.

The complement-fixation test for Johne's disease, when used on the cattle in the three dairy herds on the Field Station, has been shown to be greatly influenced by non-specific factors. The nature of these factors has not yet been determined. However, the degree of non-specificity was such that no reliance could be placed on the test results in the absence of other evidence relating to the presence of the disease.

Studies concerning the problem of interference with the tuberculin test, by Johne's disease vaccination, are continuing. Experimental non-sensitising vaccine material has been prepared and will be tested for any protective activity.

Studies on infection of laboratory animals have shown that the infection in mice can be enhanced to a limited degree by administration of the drug suramin; no enhancing effect was obtained using cortisone. Three distinct strains of mice have been examined; one strain appears very susceptible, one resistant and one intermediate, to intestinal infection with *M. johnei*. Studies are continuing with particular reference to this susceptible strain of mice. Rats have been shown to be refractory to infection even if treated with cortisone.

An experiment has been carried out to determine the pathogenesis of experimental Johne's disease. A series of calves was given a single oral dose of 200 mgms. of a culture of *M. johnei*: thereafter, pairs of animals were killed at increasing intervals of time and various tissues examined bacteriologically and histologically to trace the course of the disease process. The tonsils were found to be regularly infected in the early stages. Infection soon spread to other tissues

so that by the fourth day small numbers of *M. johnei* could be isolated from the lymph nodes far distant from the portal of entry. Lesions were detected in all calves after the first month. It appeared from this experiment that Johne's disease is initially a disease of the lymphatic system; the development of widespread infection and lesions in the intestine occurring at a later stage.

Another experiment, which is now nearing completion, is designed to compare the pathogenesis of experimental Johne's disease in calves with that in adult cows.

As *M. johnei*, which is a comparatively inert organism, appeared to enter the body readily via the tonsil and alimentary canal, it seemed important to determine if inanimate particles of similar size would do the same. Resin particles, of size 1-5 μ , were prepared, labelled with Au¹⁹⁸ and administered orally to calves. Counts of radioactivity and autoradiographs indicated the uptake of small numbers of radioactive particles, particularly into the tonsil and Peyer's patches of the small intestine as well as spread throughout the body in the reticulo-endothelial system. Radioactive particles may prove to be a valuable tool in the elucidation of various problems in the pathogenesis of infectious disease—a possibility which is being followed up.

Experiments to trace the route of entry of *M. johnei* and radioactive particles into the body of calves indicated that the tonsil is one important site. It was decided, therefore, to study the bacterial and fungal flora that are normally present in the tonsil and its associated lymph gland, the suprapharyngeal. The early results of this work have indicated the presence of a mixed bacterial population in the tonsils of cattle slaughtered in the Field Station abattoir. Occasionally, one of the bacterial species isolated from the tonsil can also be found in small numbers in the adjacent suprapharyngeal lymph gland.

Scrapie. The observation has been confirmed that the progeny of ewes and rams inoculated with scrapie-carrying tissues may develop scrapie. It has been noted, however, that the proportion of lambs out of scrapie-inoculated parents that develop scrapie is very small, and experiments are in progress to try to determine the conditions under which experimental scrapie is transmitted from parents to offspring.

Goats are being used extensively to try to characterise the scrapie agent more precisely. The high "take" in this species, when compared with sheep, has greatly facilitated these studies. It has been shown that the agent is widely distributed in the tissues of animals in the incubative and clinical stages of the disease, and its presence has been demonstrated—by goat inoculation—in brain, cerebro-spinal fluid, sciatic nerve, pituitary gland, adrenal gland, salivary gland, spleen, pancreas, liver and muscle. The remarkable resistance of the agent to various chemical and physical treatments has been confirmed and extended by experiments with goats. It has been shown that the disease may be produced in goats and sheep by oral administration of a suspension of scrapie brain. Attempts to determine the method of spread of the disease are being continued.

A study of the pathology of experimental scrapie in the goat has been completed. Important morphological changes were found only in the central nervous system. The characteristic microscopic alteration consisted of widespread non-specific neuronal degeneration accompanied by prominent astrocytosis. The topographic distribution of the changes seemed largely compatible with the clinical picture.

Polled Ayrshire Breeding Experiment. The fourth backcross generation in this long-term project began to make its appearance early this year. There were eight of these 97 per cent Ayrshire calves at the end of March, 1960.

In connection with the blood group linkage studies outlined in the previous report, blood samples from a total of 100 animals were typed by Dr. Rendel at the Genetics Department of the Royal Agricultural College, Uppsala. The cattle included 3 Ayrshire A.I. sires from the Reading Cattle Breeding Centre, 40Pp (heterozygous polled) dams of the F₁, FR₁ and FR₂ generations and 57 offspring of the FR₁, FR₂ and FR₃ generations, both Pp (heterozygous polled) and Pp (homozygous horned). Seven young Pp bulls, heterozygous at several blood group loci, were selected for the test matings with horned females. These bulls will have to produce from six to twenty offspring each—the numbers vary for the different loci involved—to determine the degree of linkage, or its absence. The majority of these calves is expected within the next ten months.

Following an invitation from the Royal Agricultural Society of England, the Field Station contributed an "educational exhibit" of polled strain derived from horned breeds of cattle at the Royal Show, held at Oxford in July, 1959. The Field Station's exhibit featured Pp females representing each successive stage in the breeding programme from the F₁ up to and including the FR₃.

Animal Ecology. It was confirmed that, in mash-fed rats restricted in their feeding to within a period of 2½ hours daily, the resident bacteria in the non-glandular part of the stomach occur as short forms without chain formation in contrast to the longer forms often with chain formation present in rats fed *ad lib*. These organisms have been identified as lactobacilli by Dr. M. Elisabeth Sharpe of the N.I.R.D. and no constant difference was observed in colonies grown from the short forms or the longer chained forms.

In sections of the stomach of stock rats, the numbers of bacilli in the non-glandular part of the stomach were variable and were sometimes very large. Here the pH varied from 4.9 to 6.4 (mean 5.55). In the glandular area, where the pH varied from 2.8 to 5.05 (mean 3.70), there was a variable number of yeasts. In contrast, in flesh fed rats, bacteria in the non-glandular part were fewer and were proteolytic, and in only one of fifteen rats were there yeasts in the glandular area.

The normal and abnormal structure and functioning of the omasum of domestic cattle have been studied.

Clinical Pathology. Routine biological tests are carried out on the normal breeding herds and flocks, and diseases occurring spontaneously in these animals receive clinical attention and investigation. Laboratory investigations are made on the more problematic diseases. Histological studies were continued on the jaundice of housed sheep associated with high liver copper storage, and on hermaphrodite goats to determine the genetic sex. Field trials were carried out of two organo-phosphorus systemic insecticides for use against ox warbles; both were found to be effective and the results have been published.

Diseases of Pigs. A study of the effect of administering streptomycin on *Bacterium coli* present in faeces and on the growth rate of piglets has been made. Results have shown that the population of organisms consists of two varieties, one sensitive and the other resistant to the antibiotic. During treatment, the

population of sensitive organisms is reduced by the selective action of the antibiotic and is replaced by the resistant varieties. When treatment is discontinued, however, the original proportion is quickly restored. These results largely confirm those found in calves previously, which showed that a permanently resistant population was not established during the administration of antibiotics.

Assays of the concentration of terramycin present in the milk of sows following oral administration before farrowing have been made.

Studies on pneumonia in pigs have continued, particularly with regard to characterisation of various histopathological changes occurring in different respiratory disease entities. Further observations have also been made on the pathology of combined infections, involving the agents of virus pneumonia, *Haemophilus*, *Pasteurella* and parasitic infections. Lesions observed in pigs are being considered in relation to pneumonic conditions caused by similar agents in other species.

In experimental work with *Haemophilus sp.* in pigs, the effects of intracheal inoculation of scaled doses of organisms have been investigated. Subsequently, the magnitude of infective dose to produce consistently sub-lethal pneumonia was determined and used in experiments on the progressive pathology of the disease. Comparisons were also made between the Mayfield (Compton) strains of *Haemophilus* and strains of *Haemophilus suis* and human *H. parainfluenzae*. The pathogenicity of *Haemophilus* for pigs when inoculated by various parenteral routes was examined and similar studies were carried out with the same cultures in a range of small laboratory animals.

The incidence of localised fibrous pleurisy in pigs killed at a local bacon factory was found to be nearly 20 per cent. This pleurisy was indistinguishable from that observed as a residual lesion in experimental *Haemophilus* infection but it has not yet been ascertained what proportion of field cases might be attributable to *Haemophilus* compared with the number associated with other agents.

The Mayfield herd at Compton has continued to remain free from virus pneumonia, eradicated in 1955. Routine examination of lungs and checks on the background health of the herd have provided valuable experience in dealing with virus pneumonia-free stock. Several other respiratory diseases have been observed, including inclusion-body rhinitis, mild lungworm infection, bacterial pneumonia and pleurisy. Since they may give rise to symptoms resembling virus pneumonia and to coughing, they must be constantly differentiated on clinical and pathological grounds from virus pneumonia to guard against its reappearance in the herd. Studies on the background health of the herd have led to observations on piglet diarrhoea and its control, infectious cystitis in sows and terminal ileitis.

Radiobiology. The study of the toxicity of 131^{131} to the dairy cow has been completed. The minimum radiation dose to the thyroid gland needed to have a deleterious effect on the animal is estimated to be of the order of 100,000 rad. Techniques are being developed for the investigation of the radiation hazard to the gut of the cow from insoluble fission products, and for physiological studies of the passage of food through the gut.

The study of the metabolism of the alkaline earth elements has been extended

to include radium, showing this element to be subject to the same discriminating processes relative to calcium, as barium, though to a greater degree.

In collaboration with the workers on Johne's disease, small inert particles labelled with ^{198}Au similar in size to the bacillus have been fed to calves and attempts are being made to label *Mycobacterium phlei* with ^{32}P for use in similar experiments.

Haematology. The study of goat's blood was completed at the end of the third year and an investigation was begun on the possible causes of the fall in haemoglobin occurring during the first few weeks of life.

Toxoplasmosis. The pathology of experimental toxoplasmosis in pregnant ewes has been studied in a conjoint experiment with Professor Beattie and his colleagues at Sheffield and Leeds.

Placental Grafts. In a previous report it was mentioned that autogenous grafts of certain parts of the rat placenta (the yolk sac) on to the omentum are liable to develop into cysts composed of a variety of tissue derivatives. Mucus-secreting epithelium organised to resemble small intestine frequently appeared side by side with skin, cartilage and bone in the same graft. It has now been shown that similar results arise when rat placental membranes are grafted into other males and females of the same rat strain. The important factor in the success of grafting is the stage of pregnancy at which the material is taken, for when transplanted on the 11th or 18th day of pregnancy success is rare, but on the 14th or 15th day many grafts take and grow vigorously. Growth of such grafts raises problems of tissue tolerance because the Wistar albino strain of rat used is insufficiently homogenous to allow adult skin to be grafted from one rat to another. Work is continuing into this aspect of the problem and also into the possibility that a successful placental membrane graft might induce some degree of tissue tolerance in the recipient rats to other tissues of the donor.

Attempts are now being made to graft other parts of the placenta. While no success has been achieved to date with the chorioallantois, grafts of the amnion and umbilical cord have grown. Similar success has followed attempts to graft other foetal tissues such as skin and intestine. In all cases the growth of the graft depends on the stage of pregnancy at which the material is taken and this time factor varies with different tissues. Such a phenomenon raises interesting problems of the control of tissue growth, development and differentiation. These are being followed up.

FOOT-AND-MOUTH DISEASE RESEARCH INSTITUTE

Pirbright, Surrey

(World Reference Laboratory for Foot-and-Mouth Disease)

Director : Ian A. Galloway, D.SC., M.R.C.V.S.

Deputy Director: J. B. Brooksby, D.SC., PH.D., M.R.C.V.S.

VACCINES

Inactivated Vaccines :

N. St. G. Hyslop, B.V.SC.,

M.R.C.V.S., D.T.V.M.

A. W. Morrow, M.A., B.SC.

G. N. Mowat, M.R.C.V.S.

I. K. M. Smith, M.SC., M.R.C.V.S.

Live Vaccines (modified strains) :

H. H. Skinner, M.R.C.V.S.

PATHOLOGY AND EXPERIMENTAL CYTOLOGY

H. Platt, PH.D., M.V.SC., M.R.C.V.S.

GENETICS

H. S. Sharpe, B.SC., PH.D.

BIOCHEMISTRY

F. Brown, M.SC., PH.D.

Miss J. Crick, M.SC.

BIOPHYSICS

C. J. Bradish, B.SC., PH.D., A.INST.P.

H. V. Thorne, B.SC., PH.D., A.R.C.S.

SEROLOGY

J. Davie, B.SC., M.R.C.V.S.

TISSUE CULTURE

W. B. Martin, PH.D., M.R.C.V.S., D.V.S.M.

DISEASE SECURITY OFFICER

H. Cronly, C.B.E., M.R.C.V.S., D.V.S.M.,
D.T.V.M.

Secretary: A. C. T. Edwards, C.B.E., B.A.

At 31st March, 1960, the scientific staff including experimental officers numbered thirty-five.

CURRENT WORK

Epidemiological Surveys. Very valuable additional information on the distribution of the different virus types has been obtained during the relevant period by the work of the Institute functioning as the World Reference Laboratory. This is assisting in the control of the disease. Outbreaks due to virus types not previously recorded in certain countries have been confirmed e.g. type Asia 1 in Syria and Lebanon (in 1957, 1958 and 1959 virus of this type was demonstrated in samples received from Israel), type O in Lebanon, Libya, Aden and Ruanda-Urundi, type S.A.T.2 in Nyasaland. Special mention may be made of the series of outbreaks in South Africa since they illustrate how a much more realistic picture of the occurrence of types is obtained if samples are received from every outbreak. In the last report, mention was made of widespread series of outbreaks in the Eastern Transvaal all due to type S.A.T.3. This was the first time that this type had been encountered in the Union and almost at the same time in Mozambique. Virus of this type was first recovered from impala and then from cattle in December, 1958, and from then until September, 1959, there was a series of outbreaks, but in 113 samples examined only type S.A.T.3 virus was demonstrated. Then in October, 1959, virus of type S.A.T.2 was found in samples from impala and also from cattle in East Transvaal and there was then a widespread series of outbreaks from October, 1959, to March, 1960. During this period over 100 samples were received and only type S.A.T.2 virus was demonstrated. The

information obtained was of great service in applying appropriate control measures.

Similarly, valuable information has been obtained in some other countries as the result of the increased activity in collection and despatch to Pirbright of samples for examination e.g. Tanganyika and Uganda. Outbreaks due to four different types A, O, S.A.T.2 and S.A.T.1 have now been confirmed in Uganda; the finding of type S.A.T.1 is of particular interest to the neighbouring country Kenya in which only O, A, C and S.A.T.2 have been detected so far. In Tanganyika from the same premises four samples were received; two were type O and two were type S.A.T.2. The detection of one or other of the two types might well have been missed if only one sample had been sent.

From July, 1958, when the Institute was recognised as the World Reference Laboratory, to the time of writing this report, over 1,300 samples from 30 different countries, excluding Great Britain, have been examined.

It is of interest that the early information which the Institute obtained from this work, of the occurrence of outbreaks due to type S.A.T.2 virus in South Africa, facilitated the arrangement of a field trial, with a live attenuated strain vaccine of type S.A.T.2 developed at Pirbright.

The survey of subtype strains, with the view to establishing a collection for reference with appropriate antisera, which is another of the functions of the World Reference Laboratory, is continuing. This is of importance in relation to epidemiological studies and vaccination. Particular attention has been paid so far to subtype O strains and recently two strains have been recognised as new subtypes. In addition some time has been spent in the examination of three S.A.T.2 type strains from three countries in Africa and these have been shown to be subtypes distinct from each other.

One of the responsibilities accepted by the World Reference Laboratory is the examination and identification for European countries of samples of virus suspected to be types other than O, A and C. This work will receive first priority. At the 28th Session of the Office International des Epizooties, the World Reference Laboratory agreed to supply to European countries on request specific antisera for the four types S.A.T.1, S.A.T.2, S.A.T.3 and Asia 1 to facilitate early recognition of these types. Once the local tests have provided a basis for suspicion that the type is other than O, A and C, the virus sample will be sent to Pirbright for full examination. As soon as there is sufficient confirmatory evidence that the outbreak is associated with a virus type other than O, A and C, this information will be transmitted to the country concerned, to the European Commission for the Control of Foot-and-Mouth Disease, to F.A.O. and to O.I.E.

The early detection of the occurrence of an outbreak of foot-and-mouth disease due to a type other than O, A or C is a matter of great importance to countries on the continent of Europe. Already the type specific antisera have been supplied to eight countries and further requests are coming in.

Genetics. In the last report, reference was made to studies that were being undertaken on the relative sensitivity of some different strains of mice to the virus of foot-and-mouth disease. These investigations are obviously of great importance since unweaned and adult mice are now used extensively in research on foot-and-mouth disease. The genetical approach to the studies of the

susceptibility of the host species is a real contribution to the quantitative study of viruses, and in particular, the development of two strains of experimental mice of high susceptibility to meet a particular need is a new approach to the problem.

In the early work, the two random-bred laboratory mouse strains in use at Pirbright were shown to differ appreciably in their susceptibility to the virus of foot-and-mouth disease when it was inoculated by the intraperitoneal route. The average variances of the estimates of susceptibility were also different. Similar studies of fourteen strains of mice, some random-bred and some in-bred, have now shown as great differences amongst them in susceptibility to the virus. When the different mouse strains were placed in order of diminishing susceptibility, it was noted that the variability in response increased as the susceptibility of the strain decreased. The use of mouse strains of low susceptibility would therefore not only diminish the possibility of detecting virus in low concentration, but also the precision of determining the end point in virus titrations. The route of inoculation is also of importance for it was found that the susceptibility of all mouse strains tested was higher when the virus was inoculated by the intramuscular route rather than the intraperitoneal. The susceptibility difference between the two routes differed with the virus strain used, but whichever route of inoculation was used, the order of susceptibility of the mouse strains was virtually the same.

It was shown that if two mouse strains were tested with a virus strain highly adapted to the less susceptible mouse strain of the two by repeated intraperitoneal passage, then the strain of mouse which had hitherto appeared to be less susceptible would now appear to be the more susceptible, provided that the route of the infection was the same as that used for adaptation by passage. When extensive tests were made with different virus strains on two strains of mice, the susceptibility difference between the strains varied considerably, even when the viruses were ones which had never been passaged in mice. This indicates that virus strains in nature vary greatly genetically in their ability to infect a particular mouse strain.

Two new mouse strains combining high susceptibility with other desirable characters, have been developed from crosses between existing strains. Continued breeding and selection should on the basis of tests at each generation bring further improvements in both strains. The breeding experiments indicate the genetic control of susceptibility to be complex.

Biochemistry

Fluorocarbon. Fluorinated hydrocarbons have been used for the purification of viruses and the method has been used to purify several animal viruses e.g. those of poliomyelitis, vaccinia, influenza, mumps and the Coxsackie and Echo viruses. It has been reported that virus antigens differ considerably in their susceptibilities to fluorocarbon treatment. The complement fixing antigens of Coxsackie and poliomyelitis virus tolerated successive treatments without loss of titre but those of mumps and influenza did not.

Studies made at this Institute on the effect of such treatment on the virus of foot-and-mouth disease have shown that the larger infective virus particle (20 mu component) is unaffected while the smaller non-infective virus component (7 mu) is completely removed from virus suspensions. It has thus been pos-

sible by another method to estimate the contributions of each of the two virus components to the total complement fixing activity of a virus suspension. The retention of infectivity of virus suspensions treated with fluorocarbon (Arcton) indicates that lipids do not form part of the essential structure of the infective component. In the last report attention was drawn to work which had shown that the virus of foot-and-mouth disease is highly resistant to ionic detergents including the anionic detergent sodium dodecyl sulphate (S.D.S.) which supported this view and which is in line with the known resistance of the virus to naturally occurring detergents and to the lipid-extracting solvents ether, acetone, ethanol and butanol.

It has been shown also that fluorocarbon will dissociate the virus of foot-and-mouth disease from an apparently neutral mixture with immune serum as determined by intraperitoneal inoculation of unweaned mice. This suggests that the virus neutralising activity of immune serum may depend on its preventing virus from reaching or attaching to susceptible cells in the body. A high yield of infectivity could be recovered so that the virus particle does not appear to be adversely affected.

Infective Ribonucleic Acid and Mechanism of Infection of Cells. More information is required concerning the mechanism by which animal cells are infected by viruses.

Some recent work with the virus of foot-and-mouth disease has shown that although the virus attaches rapidly to pig kidney tissue culture cells in suspension with considerable overall loss of virus infectivity, the amount of infective ribonucleic acid (R.N.A.) which can be obtained from the cells and the supernatant fluid after adsorption is the same as the amount extractable from the initial infecting virus.

Infective R.N.A. could be detected in pig kidney cells within five minutes of contact with the virus. This infective R.N.A. was completely destroyed by ribonuclease showing that it was no longer in the virus particle which is not itself susceptible to the action of the enzyme. The R.N.A. which was equivalent to that which could be extracted from the initial virus was recoverable from the cells five minutes after addition of the virus showing that the process of infection was complete by that time.

On the other hand it was found that only about 50 per cent of the non-nucleic and specific protein of the virus which was lost from the virus suspension could be recovered from the cells. Using the criteria of agar diffusion and complement fixation tests, the virus component which could be extracted from the cells appeared to be identical with the non-infective small component (7 mu) of the virus. This result was obtained whether infection of the cells was carried out with an unfractionated virus suspension or the purified large component of the virus (20 mu). It seems likely therefore that in the process of infection of the cells with the virus, the core of infective R.N.A. is rapidly injected into the cells and the protein coat disintegrates into sub-units identical with the 7 mu component.

ANIMAL DISEASES RESEARCH ASSOCIATION

Moredun Institute, Gilmerton, Edinburgh, 9

Director: John T. Stamp, D.SC., M.R.C.V.S., F.R.S.E.

MICROBIOLOGY

Head of Department : J. G. Brotherston,
F.R.C.V.S., DIP.BACT.

A. Foggie, B.SC., PH.D., M.R.C.V.S.
J. M. K. Mackay, PH.D., M.R.C.V.S.
G. R. Smith, PH.D., M.R.C.V.S., D.V.S.M.,
DIP.BACT.

ROUTINE PATHOLOGY

D. I. Nisbet, B.SC., PH.D., M.R.C.V.S.

PHYSICAL CHEMISTRY

D. L. Mould, B.SC., PH.D.

CLINICAL INVESTIGATIONS

C. C. Renwick, M.R.C.V.S., D.T.V.M.

NEUROPATHOLOGY

Head of Department : I. Zlotnik,
B.V.SC., PH.D., M.R.C.V.S.

R. M. Barlow, B.SC., D.V.M. & S.,
M.R.C.V.S.

BIOCHEMISTRY

Head of Department : E. J. Butler,
M.A., B.SC., D.PHIL., A.R.I.C.

A. C. Field, M.V.SC., M.R.C.V.S.
B. S. W. Smith, M.SC., PH.D., A.R.I.C.

PARASITOLOGY

Head of Department : J. A. Campbell,
B.A., PH.D., M.R.C.V.S.

M. G. Christie, B.A.
A. C. Gardiner, B.SC.
E. C. Pelham-Clinton, B.A.

Secretary: D. M. Cameron, A.C.I.S.

The work of the Institute is to investigate the factors concerned in the aetiology of diseases in farm animals and to discover means for the prevention of disease.

The scientific and experimental staff at 31st March, 1960, numbered thirty-one.

CURRENT WORK

Johne's Disease. Brief reference was made in the last report to the study of bacterial counts in the tissues of vaccinated and non-protected animals. There is now evidence to suggest that immunity to Johne's disease operates by restricting the multiplication of the causal organism in the gut and that host-resistance can be expressed by comparing the bacterial numbers in the bowel of vaccinated and non-vaccinated animals. This is now possible since cultural techniques have been developed for determining the viable count of *Mycobacterium johnei* in the intestine of sheep and laboratory animals which follow the same methods as those previously reported for tissues other than the intestine. In this work week-old lambs have been used successfully to test the ability of vaccines to prevent the progress of infection following oral administration of *M. johnei*. Other experiments with 3- to 4-month-old sheep gave similar results. Experiments to test the value of various vaccines prepared from fractions of the Johne bacillus are now in progress.

Preliminary work with Syrian hamsters suggests that more than 60 per cent are susceptible to oral infection with *M. johnei*; these animals may well prove to be of more convenient experimental animals than sheep or cattle for further work on vaccines.

Pneumonia and Septicaemia of Sheep. In last year's report it was shown that two types of the organism called *Pasteurella haemolytica* are important

in this disease, Type A and Type T, this classification being based on growth characteristics in laboratory culture. The classification of *Past. haemolytica* into two types has led to further discoveries concerning the pathogenicity of the organism. Three forms of disease due to *Past. haemolytica* are now recognised in sheep:—

- (1) *Pneumonia due to Type A bacteria.* Infection is usually confined to the chest but occasionally some organisms are found elsewhere. A widespread dissemination of organisms may be associated with a very severe pneumonia but this occurs rarely.
- (2) *Septicaemia in 6- to 12-month-old lambs due to Type T bacteria.* Massive numbers of bacteria have been demonstrated in the lung, liver and spleen of affected animals.
- (3) *Septicaemia in very young lambs caused by Type A bacteria and characterised by sudden death.* Most cases have been seen in lambs 3 weeks old or under. The lesions vary but are associated with massive numbers of bacteria.

Three-week-old lambs were highly susceptible to experimental infection with Type A strains derived from cases of (1) and (3) whereas older sheep were resistant. Type T strains were of lower virulence and were cleared more quickly from the tissues of 7-month-old lambs than from the tissues of 18-month-old sheep. Toxicity of *Past. haemolytica* in the natural and experimental disease is now being investigated.

Tick-borne Fever. This disease can only be transmitted naturally from sheep to sheep by the sheep tick. The causal agent is a small microbe which can be seen microscopically in the blood of affected sheep, but its cultivation in the laboratory has as yet not been achieved. Tick-borne fever is definitely associated with one form of abortion in ewes and it is probably associated with tick pyaemia or "cripples." The disease is also the cause of a febrile infection of cattle in which loss of milk yield can be considerable. Numerous attempts have been made to adapt the organisms to guinea-pigs and mice with the object of developing a guinea-pig or mouse adapted strain organism which might be non-virulent to the sheep and yet be capable of immunising sheep and cattle against the natural disease. The agent is at present in its 40th serial passage in guinea-pigs, and its 20th serial passage in mice.

Scrapie. Numerous experiments previously reported suggest that the causal factor of scrapie is a replicating or virus-like agent. One of the first steps in the investigation of an agent, supposed to be a virus, is to attempt to characterise it by showing that it has specific morphological, physical and serological characteristics. Our attempts to demonstrate such specific characteristics in the case of the transmissible factor of scrapie have been singularly unsuccessful. The most outstanding characteristic of the disease is the apparent resistance of the agent to boiling, numerous experiments having shown that scrapie can still be transmitted to both sheep and goats even when the transmitting material has been boiled for 30 minutes and more. Before accepting that scrapie is due to a virus-like agent which can withstand boiling it has been essential to investigate the problem further, especially the question as to whether the boiled material might simply be acting as a stimulating agent to some latent scrapie factor in our experimental sheep. Numerous experiments

to investigate this point have been carried out, but up to the present they have produced no evidence that the scrapie agent is other than a self-replicating substance or virus which can withstand boiling. This work demonstrates the complexity of but one aspect of the problem of characterising the agent of scrapie.

Agar diffusion techniques and fluorescent dyes are being used in numerous attempts to demonstrate specific antibody responses in the serum of inoculated animals. Considerable effort is also being made to grow the scrapie agent in tissue culture. Electron microscopy is being used to establish the presence or absence of virus-like particles in tissues of sheep and goats suffering from scrapie.

Hypomagnesaemia. Special mention may be made of studies to determine the ruminant's dietary requirements of magnesium which have, in turn, necessitated the determination of the availability of magnesium in feedingstuffs and supplements. The procedures which have been developed to make these measurements have been mainly indirect. The results suggest that the efficiency with which ruminants on a constant diet are able to utilise magnesium in pasture and hay is very low and variable and rarely exceeds 25 per cent of that in the food. A sudden change in the nature of the diet, e.g. from dry to wet feed, appears to reduce the efficiency of utilisation even further. More direct methods of estimating availability of magnesium by using radioactive magnesium have been tried, but the results are disappointing since the radioactive magnesium did not distribute itself evenly with the ordinary magnesium in the food. Radioactive magnesium has also been used to trace the fate of magnesium in the body of sheep. These experiments show that the adult ruminant is unable to build up appreciable reserves of magnesium in any of its tissues.

Diseases of Bone. The collection of diseases of bones of sheep from the field has continued and sufficient material has been obtained for the conditions to be classified according to their pathology. Structural changes have been related to chemical analyses of bones and blood.

Stomach and Intestinal Worms of Sheep. It has become increasingly evident in recent years that the losses through parasitism are not necessarily directly proportional to the "dirtiness" of the ground as had been previously thought. In particular the phenomenon of host-resistance is now recognised as a major element in the regulation of parasite populations and in the epidemiology of the diseases they cause. One important aspect of resistance in the host is the suppression of larval development leading to the accumulation of potentially damaging latent parasites. Housed sheep at the Institute have been frequently observed developing heavy egg-laying worm populations after months indoors, and it has been proven that this occurs when the conditions are meticulously controlled to prevent the animals' exposure to infective larvae. Such animals after months of apparent freedom from worms rapidly become sick and may even die with typical symptoms of worm infestation. Large-scale experiments have been carried out to study the size and course of *Haemonchus contortus* infestations produced by varying levels of larval ingestion ranging from 10 to 1,000 larvae per day for a period of three months. At the high level of infestation the majority of the animals produced a remarkably uniform picture of an initial 6 to 8 week phase of egg production which

terminated before the end of the larval administration period. This was followed some three months later by a secondary, more protracted, phase of egg production extending to upwards of six months. At the lower levels of infestation the findings were less consistent, some animals approximating to the course described, and others carrying continuously patent infestations throughout the whole period. Concurrent observations on pathogenicity and growth have revealed that damage is sustained during both the primary and recurrent phases of infestation and that this is commensurate with egg production. Serological studies are in progress with the aim of relating the immunological and parasitological aspects of the infestations. The experiments have, we believe, thrown some important new light on our ideas of host-resistance and pathology and worm population dynamics.

Another aspect of host-resistance is the possibility of change in the local tissues which makes them unfavourable for parasite establishment. This is being studied in *Nippostrongylus muris* infestations of rats. Results to date have failed to substantiate suggestions by earlier workers that after the 18th day or so when the existing population has run its course there are secondary increases in the intestinal populations. Moreover, there has not been evidence to support earlier claims that superinfestation of infested, or re-infestation of immune rats, results in worms attaching at different sites further down the small intestine. Although these studies so far tend to suggest that general immunity is more important than local, if indeed the latter exists, the work provides useful experience for later extension to sheep parasite problems.

Work has continued on *Nematodirus* and the earlier problem of maintaining supplies of infective larvae has been largely solved. In particular, the effects of temperature and humidity on development have been elucidated and, by use of the appropriate sequence, hatching of both species can be induced without resort to mechanical assault on the egg. In general, but not in all details, the findings support existing views on the epidemiology of *N. battus* and resolve the contradictions in the literature on *N. filicollis*.

ANIMAL PHYSIOLOGY AND NUTRITION

ROWETT RESEARCH INSTITUTE

Bucksburn, Aberdeen

Director: D. P. Cuthbertson,

C.B.E., M.D., D.SC., D.SC. (RUTGERS), LL.D., F.R.S.E.

Deputy Director: A. T. Phillipson, M.A., PH.D., D.V.SC., M.R.C.V.S., F.R.S.E.

PROTEIN AND LIPID CHEMISTRY

Head of Department: R. L. M. Synge,
B.A., PH.D., F.R.I.C., F.R.S.

PROTEINS

E. I. McDougall, B.SC., PH.D., A.R.I.C.
Miss M. I. Chalmers, B.SC., PH.D.
F. J. Bealing, B.SC., PH.D.

LIPID CHEMISTRY

G. A. Garton, D.SC., PH.D.
A. K. Lough, PH.D., A.R.I.C., A.H.-W.C.

MICROBIOLOGY

Head of Department: P. N. Hobson,
B.SC., PH.D., F.R.I.C.
B. H. Howard, B.SC., PH.D., A.R.I.C.

ENZYMOLGY

Head of Department: G. A. Levvy,
D.SC., PH.D., F.R.I.C.
C. A. Marsh, B.SC., PH.D., A.R.C.S.
J. Conchie, B.SC., PH.D.
G. Halliwell, M.SC., PH.D.

PHYSIOLOGY

Head of Department: A. T. Phillipson,
M.A., PH.D., D.V.SC., M.R.C.V.S., F.R.S.E.
J. D. Puller, B.SC., PH.D.
T. M. Sutherland, B.SC., PH.D.
J. G. Gordon, B.SC.(AGRIC.), PH.D.
A. Dobson, B.A., PH.D.
R. W. Ash, B.SC., B.SC.(VET.SCI.), M.R.C.V.S.
R. N. B. Kay, M.A., PH.D.

Secretary: W. Middleton, N.D.A.

DIRECTOR'S UNIT

D. P. Cuthbertson, C.B.E., M.D., D.SC.,
D.SC.(RUTGERS), LL.D., F.R.S.E.

PATHOLOGY

Head of Department: J. J. Bullen,
PH.D., M.R.C.V.S.
B. F. Fell, B.SC., M.R.C.V.S.
F. White, B.SC., B.SC.(VET.SCI.), M.R.C.V.S.

HELMINTHOLOGY

G. C. Hunter, B.SC.

APPLIED BIOCHEMISTRY

Head of Department: J. Duckworth,
B.S.A., D.SC., F.R.S.E.*
J. Davidson, B.SC., PH.D., A.R.I.C.
Miss G. M. Ellinger, B.SC., PH.D., A.R.I.C.
C. F. Mills, M.SC., PH.D., A.R.I.C.
E. Cresswell, M.SC., PH.D.
A. A. Woodham, B.SC., PH.D., A.R.I.C.

APPLIED NUTRITION

Head of Department: J. A. Crichton,
M.B.E., M.A., B.SC.(AGRIC.), F.R.S.E.
I. A. McK. Lucas, B.SC.(AGRIC.), M.SC.
J. L. Corbett, B.SC.(AGRIC.), M.AGR.SC.
T. R. Preston, B.SC.(AGRIC.), PH.D.
G. A. Lodge, B.SC.(AGRIC.), PH.D.

STATISTICS

Head of Department: A. W. Boyne, B.SC.
I. McDonald, M.A.

DUTHIE EXPERIMENTAL STOCK FARM
W. Thomson

Librarian: J. C. R. Yeats, A.L.A.

* Died 11th April, 1960

The work of the Institute is directed to an understanding of the energy and material requirements of animals of agricultural importance and the factors influencing their supply to the tissues. A study is also made of the relationship of diet to metabolic disorders and other underlying causes of

susceptibility to disease. On the basis of the new knowledge obtained and of researches elsewhere, exploration is made of the best systems of feeding live-stock and of the influence of environment on their utilisation. Man's food requirements are also kept under review. The Commonwealth Bureau of Animal Nutrition is located at the Institute.

The scientific and experimental officer staff of the Institute at 31st March, 1960, numbered eighty-eight.

CURRENT WORK

Protein and Lipid Chemistry. Work on the protein metabolism of the lactating ruminant has continued with experiments on the protein-sparing effect of carbohydrate in the diet, and on the effect of lipids on ammonia production in the rumen. A cannula has been developed in collaboration with the Physiology Department for obtaining uncontaminated samples of rumen contents as they enter the abomasum, which should prove useful in these investigations.

In the study of nitrogenous constituents of leaves it appears possible that the carbon dioxide fixing enzyme may be isolated; cellulose phosphate promises to be useful for chromatographic separation of complex peptide mixtures and considerable progress has been made in the purification of a forage leaf proteinase.

A complex mixture of peptide-like compounds containing most of the common amino acids obtained from rye grass has been partially fractionated.

The degree of unsaturation of the inner- and outer-back fats of pigs was not affected by the inclusion of α -tocopherol in the diet, whether fat-free or not. On the basis of plasma tocopherol levels, the vitamin was absorbed as efficiently from a diet almost devoid of fat as from one containing 5 per cent lard.

Small amounts of albumin-bound stearate-1- ^{14}C , added to blood perfusing an intact isolated cow's udder, were rapidly incorporated into triglyceride in the secretory tissue of the gland; some conversion of stearic acid to oleic was also observed.

Further studies on lipolysis and hydrogenation of unsaturated fatty acids by rumen micro-organisms were reported. When incubated with sheep rumen contents various triglycerides were extensively hydrolysed.

Of the total fatty acids of the lipids of mixed pasture grass linolenic acid comprised 62 per cent, linoleic 13 per cent and palmitic 16 per cent.

Microbiology. Strictly anaerobic rumen bacteria capable of hydrolysing triglycerides of higher fatty acids and/or fermenting glycerol have been isolated and characterised. These are probably responsible for a major portion of the breakdown of foodstuff triglycerides which recent work at the Institute has shown takes place in the rumen. After investigation of protein breakdown by whole rumen contents suitable media for isolation of proteolytic bacteria were devised and the investigation of pure cultures of such bacteria is proceeding. The significance of ciliate protozoa in normal rumen metabolism is steadily being revealed.

Enzymology. Studies of the intracellular distribution of mammalian β -glucuronidase and of other glycosidases probably involved in mucopoly-

saccharide breakdown, have been continued. In normal tissues these enzymes are usually confined to cytoplasmic granules, whereas in mouse tumours β -glucuronidases is largely free in the cell cytoplasm. To demonstrate these effects, homogenisation techniques were rigidly controlled, since tissues differed greatly in fragility. Mammalian fucosidases are also being investigated, using new synthetic substrates; whereas α -L and β -D-fucosidase activities were widespread, neither β -L nor α -D-fucosidase could be detected.

In the process of cellulose solubilisation by cell-free extracts of *Myrothecium verrucaria* the enzymes responsible were found to be strongly adsorbed on to the substrate.

Physiology. A method of determining the fatty acid production within the rumen and reticulum has been developed. The rumen contents of sheep fed on a ground ration of pelleted food are sufficiently fluid to be circulated by means of a pump, the inlet and outlet of which are fixed in the rumen through the cannula. The introduction of isotopically labelled volatile fatty acids allows the rate at which these disappear from the rumen, and the rate at which now unlabelled acid is formed, to be calculated.

Comparisons of the parotid and mixed salivas of both sheep and cattle indicate that the decrease in sodium and increase in potassium concentrations of parotid saliva that occur when the animal is depleted of sodium, and which is the result of a greater output of aldosterone by the adrenal cortex, can be detected within defined limits in the mixed saliva. During stall feeding the saliva remained within normal limits but when grazing early summer grass certain animals showed detectable changes similar to those expected from a greater secretion of adrenal corticoids.

Sheep previously studied in the controlled temperature and light experimental rooms, where their patterns of excretion of sodium, potassium and calcium were known, were then subjected to bilateral adrenalectomy. Their subsequent behaviour when given different levels of steroids with mineralo- or glucocorticoid activities has been recorded. While the full results have still to be assessed it was noted that when administration was finally withdrawn no pronounced ketonaemia developed.

The volume of food entering the abomasum and its contents of fatty acid are important in stimulating the secretion of acid from the fundic glands while excess acidity of the contents of the organ is inhibitory. As the acidity of the material leaving the abomasum and entering the duodenum does not vary greatly in normally feeding sheep, it is probable that the volume of materials entering and leaving the organ and the secretion of acid are integrated.

The excretion of calcium and magnesium in the alimentary secretions of the sheep and the absorption of these elements from the intestine have been studied. Further work using the duodenal by-pass technique is in progress.

Studies on the heat output by bacon pigs and adult sheep are progressing in the new direct calorimeters. An experiment on the effects of different feeds, the animal and the season on the concentration of starch- and glucose-fermenting bacteria in the rumen of sheep is nearing its completion. In addition, studies on the effects of insulin on the isolated rat heart are in progress.

Director's Unit. In collaboration with Dr. A. S. McFarlane of the Medical Research Council and the Physiology Department the presence of albumin

in loops of sheep small intestine has been demonstrated *in vivo* using intravenous ^{131}I -albumin and, as control, ^{131}I .

The intravenous injection of citrated whole blood at the time of fracture of a femur had only a small effect in reducing the characteristic catabolic effect due to injury in the rat. The injection of citrated blood intravenously to intact rats gave no response.

Administration of the antimetabolite neopyrithiamine (200 μg) to pregnant rats from the 2nd to 13th days of gestation caused paralysis of the mother's limbs. Injection of 10 mg. thiamine resulted in complete recovery and foetuses were born at full term which surprisingly appeared normal macroscopically.

Hill sheep contain much more ^{90}Sr arising from fall-out than other breeds of commercial importance. Of the factors suggested which probably contribute to this comparatively large uptake of ^{90}Sr are the low calcium and phosphorus intakes of the sheep coupled with the severe drain on the calcium reserves in the case of breeding hill ewes.

An experiment was started at the beginning of 1959 to study the metabolism of ^{45}Ca and ^{89}Sr in Blackface ewes when non-pregnant and at various stages of pregnancy and lactation. Some are maintained on a diet adequate in calcium and phosphorus, while others are fed on a diet low in these elements. The ewes maintained on the deficient diet appear to absorb more of both nuclides and to absorb a slightly higher proportion of radio-strontium. Correspondingly less of the latter appears in the faeces of the Ca and P deficient animals. Discrimination against Sr in the kidneys of the low-Ca and P group is not diminished and, in fact, tends to be somewhat higher than in the control animals. Discrimination against Sr in the mammary gland appears to be dependent upon the yield of milk, being greater when the milk yield is high. Some of the results indicate that although single dose experiments are useful when comparing the behaviour of two labelled elements, it is likely that this technique is liable to error when the quantitative metabolism of a single element is being studied. Thus when absorption from the gut or excretion into it is being studied, no allowance is normally made for the proportion of material passing through the gutwall by physical ion-exchange. It is hoped to study this process in relation to Ca and Sr absorption and excretion *in vivo* by means of various intestinal loop preparations.

Pathology. Work on the bacteriostatic effect of sera on *Clostridium welchii* in embryonated eggs is virtually complete. The phenomenon is being studied *in vitro*. The first stage of a study of gas gangrene has been completed. The alpha toxin of *Cl. welchii* has been prepared as a relatively pure antigen. The large scale apparatus for zone electrophoresis is under construction. Work on antibody production in transplanted tissue continues.

Histological studies are in progress on swayback of lambs and factors affecting the integrity of the intestinal mucosa. Work on the permeability of the intestine to circulating anti-toxin has been completed. The investigation on immunity to helminths continues. Work on immunity to *Corynebacterium pyogenes* is completed while a start has been made on a serological classification of bovine staphylococci.

Applied Biochemistry. Studies of the relationships of diet to bone metabolism and dental disorders in sheep have been continued with experiments

to contrast the patterns of mineral disturbance in the teeth and skeleton on diets deficient in calcium or phosphorus and vitamin D. Factors affecting vitamin D levels in sheep blood are also being investigated.

Nervous tissue degeneration has again been induced in lambs of ewes fed diets high in molybdenum and sulphur. The latter type of diet is known to restrict copper utilisation and this result confirms the findings of last year. Studies of the influence of molybdenum on copper distribution within tissues has begun.

Laboratory tests for predicting quality in protein concentrates continue to be studied and developed with emphasis on shortening the solubility test for determining protein quality. The nutritive value of samples of leaf protein concentrate prepared at Rothamsted has been assessed by growth tests with chicks, rats and pigs. The value was similar to that of soyabean protein for chicks and rats, and to fish meal protein for pigs.

Amino acid supplementation of experimental chick rations has been used to determine which amino acid limits the value of protein concentrates as supplements to cereal proteins. When groundnut meal contributed 3 per cent out of 11 per cent, total dietary protein lysine was the first and methionine the second limiting amino acid. However with 9 per cent groundnut protein in 17 per cent total dietary protein this order was reversed.

With laying hens housed intensively and fed low-protein diets, the addition of small amounts of methionine either alone or with lysine increased the value of a poor quality (as measured by a chick growth test) groundnut protein towards that of a white fish meal protein.

A study has been made of the relationship between dietary caloric density and the body composition of table birds from a fast-growing broiler strain.

In studies on the value of supplementary amino acids for pigs it has been shown that at low dietary protein levels nitrogen retention in young pigs was as good on diets containing supplementary groundnut protein plus lysine as on those containing supplementary fish meal protein. Some adverse effects were noted with methionine.

Applied Nutrition. The experiment on varying planes of nutrition during the rearing period of dairy cattle followed by the officially recommended level of feeding during lactation has shown that onset of first oestrus is closely correlated with body size and that a high plane followed by a low plane adversely affects milk yield (F.C.M.) during first and second lactations. The nutrition of the sow during pregnancy and lactation is also under study.

A composite ration of concentrates and milled roughage fed in self feeders has given promising results in producing fat cattle at 12-14 months of age. Estimates of the intake of extensively grazed cattle have shown that maintenance requirements on pasture are similar to those of stall-fed animals. The use of chronic oxid impregnated paper in digestibility work has been taken up by research centres throughout the world.

The calcium requirements of young pigs and the effect of copper sulphate as a growth stimulant are being studied in more detail. New investigations include the effects of checks in growth and a survey of the quality of pigs sold as baconers.

Statistics. Workers in other departments were advised on the design of their experiments, and their results statistically analysed and interpreted. The section has participated in the activities of A.R.C. Working Parties.

Duthie Experimental Stock Farm. An outbreak of swayback affecting 18 out of 226 Greyface lambs (Border Leicester-Scottish Blackface) appeared on the Institute's farm. The administration of copper to 80 lambs unaffected with swayback over an eight-week period and, starting at 6-9 weeks of age, gave a significant growth response over the same number left untreated. This experiment is being repeated in the current year.

Methods of increasing production are being pursued. Western Wolths Ryegrass treated as an arable crop has promise of giving a heavy crop for silage followed by autumn grazing. The establishment of pastures by direct re-seeding is being compared with those undersown with barley.

Methods of wintering of hill ewe hogs are being studied in co-operation with the Metabolism Department.

There is evidence that the presence of vasectomised rams during the flushing of the ewes brings the ewes into oestrus more quickly. This is being further investigated on a field scale.

A.R.C. INSTITUTE OF ANIMAL PHYSIOLOGY

Babraham, Cambridge

Director: J. H. Gaddum, M.A., SC.D., M.R.C.S., L.R.C.P., F.R.S., F.R.S.E.

Deputy Director: Sir Alan N. Drury, C.B.E., M.A., M.D., F.R.C.P., F.R.S.

PHYSIOLOGY

Head of Department: Vacant

Miss C. O. Hebb, M.A., PH.D.

J. Bligh, B.SC., PH.D.

K. J. Hill, M.V.SC., M.R.C.V.S.

K. Krnjevic, M.B., CH.B., B.SC., PH.D.

J. L. Linzell, B.SC., PH.D., M.R.C.V.S.

L. E. Mount, M.D., C.M., M.B., B.S.

J. S. Perry, B.SC., PH.D.

I. W. Rowlands, M.SC., PH.D.

K. F. Hosie, B.SC., PH.D., M.R.C.V.S.

J. F. Mitchell, B.SC., PH.D.

BIOCHEMISTRY

Head of Department: G. D. Greville,
M.A., PH.D., F.R.I.C.

V. P. Whittaker, M.A., D.PHIL.

R. M. C. Dawson, D.SC., PH.D.

D. B. Lindsay, M.A., B.SC., D.PHIL.

J. L. Mangan, M.SC., PH.D.

J. Y. F. Paterson, B.SC., PH.D.

P. F. V. Ward, M.A., B.SC., D.PHIL.

EXPERIMENTAL PATHOLOGY

Head of Department: Sir Alan Drury,
C.B.E., M.A., M.D., F.R.C.P., F.R.S.

A. D. Bangham, M.B., B.S., M.R.C.S., L.R.C.P.

E. J. H. Ford, M.V.SC., M.R.C.V.S.

A. E. Pierce, M.SC., PH.D., F.R.C.V.S., D.V.S.M.

D. C. Hardwick, B.SC., PH.D.

Secretary: E. Norris, B.COMM.

Librarian: D. W. Butcher, M.A.

Farm Manager: T. M. Fulton

The Institute is devoted to the study of the physiology of normal animals with especial emphasis on sheep, goats, cattle and pigs.

On 31st March, 1960, the scientific and experimental staff numbered fifty-seven.

CURRENT WORK

Physiology. The effects of body size, age, feeding levels and low body temperatures on metabolism and survival in new-born and young pigs are being examined; underfeeding produced lasting reductions in body temperature and basal metabolic rate. It is proposed to extend this work to larger pigs exposed to varying climatic conditions. A building suitable for this work has been designed.

Attempts have been made to start a second pregnancy in guinea-pigs already pregnant on one side (superfoetation). Ovulation was induced and semen was injected intraperitoneally; fertilisation and early cleavage occurred.

Previous work showed that there is a serious loss of life among embryo pigs inside the sow. It has now been found that most of this loss occurs at an early stage before the embryos become implanted in the uterus.

The study of temperature regulation in the sheep has been continued. It has been found that the panting which occurs when the humidity of the air is high does not depend on an increase of the deep body temperature. Sheep are subject to occasional spontaneous attacks of sweating all over. This phenomenon, which can be imitated by the injection of adrenaline, has been studied.

Further work on the factors influencing gastric (abomasal) secretion in sheep has shown that the volatile fatty acids have a marked secretagogue effect. The daily production of bile and its composition have been studied under various conditions and a well-defined bile-salt circulation demonstrated in the sheep. Experiments have been started in collaboration with Dr. A. Care, and the Animal Health Trust, on the absorption of magnesium from the digestive tract of the sheep; its absorption from the rumen has been demonstrated.

Experiments with conscious goats unexpectedly showed that during lactation the udder consumes much more glucose than acetate. This finding was confirmed and extended in isolated udders, using methods of perfusion which have been developed during recent years, and which have been further improved. The experiments showed that acetate is only essential for normal fat production, but that, without glucose, milk secretion stops altogether.

Quantitative studies have shown that when the nerve to a voluntary muscle is stimulated at a physiological rate the amount of acetylcholine released is about equal to the amount which causes contraction when applied by electrophoresis to the motor end plates. In previous work there was an awkward discrepancy between these two estimates.

When suitable fluids containing eserine are kept in contact with the surface of the cortex of an anaesthetised sheep for some minutes, small quantities of acetylcholine diffuse out and can be detected by suitable methods. The rate of release measured by this technique has been found to be directly related to the electrical activity of the cortex. It is increased by directly stimulating the cortex, or by stimulating the appropriate sensory pathways, or by transcallosal stimulation. It was also increased when local anaesthetics were applied to a small area of the cortex on the other side.

Estimates of choline acetylase in peripheral nerves after section support the theory that this enzyme is manufactured in the perikaryon and transported down the axon attached to some growing structural component.

The late toxic effects of certain organophosphorus compounds have been studied in experiments on hens. These compounds cause degeneration of the nerves, but it has been found that, while triorthocresyl phosphate causes paralysis in hens much as it does in man, triparaethylphenyl phosphate causes quite different symptoms, which appear to be due to an action on the central nervous system; this is confirmed by histological studies.

Biochemistry. In continuation of the work on naturally-occurring fluorine compounds, the constitution of the toxic long-chain fluorofatty acid present in the seeds of the West African plant *Dichapetalum toxicarium*, which poisons cattle in Sierra Leone, has been determined. The techniques employed included infra-red analysis, nuclear magnetic resonance measurements (in collaboration with Dr. N. Sheppard of Cambridge University) and vapour-phase chromatography using a Martin gas-density meter as detector. The compound was proved to be ω -fluoro-cis-8-9-octadecenoic acid. In the course of the isolation from the seeds, another saturated fluorofatty acid was found, the constitution of which is not yet known. The chemistry of fluorocitric acid was elucidated further: the various products of the hydrolysis of triethyl fluorocitrate were studied and optimum conditions found for the production of ($\pm$)-fluorocitric acid. The inhibitory effects of purified synthetic and biosynthetic samples of this acid on the enzyme aconitase were compared. Improved methods for the determination of fluoride in microgram amounts and of fluorocitric acid have been devised.

Work has continued on the biochemistry of synaptic transmission, essential for the better understanding of the action on the central nervous system of drugs and toxins. A subcellular fraction of brain tissue has been isolated which contains most of the bound acetylcholine and other substances believed to be involved in synaptic transmission. Preliminary electron microscope studies suggest that this fraction is rich in synaptic vesicles and broken-off nerve endings.

A micromethod has been developed for assaying 14 phospholipids in a small sample of tissue. This has been applied to sheep tissues, rumen micro-organisms and erythrocyte ghosts. The erythrocytes of ruminants and non-ruminants differ markedly in their choline phospholipid composition. A new phospholipid designated triphosphoinositide has been isolated from ox brain in collaboration with Dr. J. C. Dittmer of Los Angeles and identified as diacylglycerolphosphoryl inositoldiphosphate. In a study of the mechanism of the attack of lipolytic enzymes on surfaces in collaboration with the Experimental Pathology Department and Mr. J. B. Davenport of Sydney, the action of the α toxin of *Clostridium welchii* has been found to depend on the charge on the substrate. Inositol metabolism in sheep thyroid has been investigated, and inositol levels in endocrine glands of rats in various conditions determined (in collaboration with Dr. N. Freinkel of Boston).

An automatic amino-acid analyser has been constructed. Using identical twin-cattle, quantitative aspects of proteolysis and deamination in the rumen are being studied. The chemical composition of bovine salivary mucoprotein has been determined.

A sulphate-reducing bacterium which is related to *Desulphovibrio orientis* and has similar properties to free-living *Desulphovibrio* spp. has been isolated

from the sheep rumen. The maintenance of sheep rumen oligotrich protozoa (principally *Entodinia* spp.) has been further facilitated.

Continuous infusion of radioactive acetate has been used in the study of the metabolism of this substance in sheep. Utilisation rates were found to be altered by changes in carbohydrate metabolism, such as those resulting from infusion of glucose or insulin. About 6 per cent of the expired CO₂ is derived from direct oxidation of acetate in the fasting sheep, and 35 per cent or more during the active absorption of acetate after feeding.

Experimental Pathology. Experiments on the chemical and physico-chemical properties of cell surfaces (blood, spermatozoa and model cells) continue. In particular, the nature of the ionic groups on polymorphonuclear cells with reference to their adhesive properties, and the surface charge conditions required for the interaction of an enzyme (lecithinase C α toxin *Cl. welchii*) with its lipid substrate lecithin, have been investigated. This latter system was chosen because of the invariable presence of lecithin in cell membranes.

Electrophoretic, ultracentrifuge, immunological and genetic characteristics have been studied in parallel to identify the colostrum components and to compare them with those contributing to the proteinuria of the new-born calf. The colostral β -lactoglobulins have been shown to be absorbed from the small intestine, in addition to the immune lactoglobulin, and to be subsequently eliminated selectively in the urine giving rise to a transient β -lactoglobulinuria which persists only during that period when the intestine is permeable to undegraded protein.

An immunological study of coccidiosis in the chicken has been undertaken in collaboration with the Houghton Poultry Research Station.

The activity of enzymes in the serum and liver was studied in normal cattle near to parturition and in cattle and sheep poisoned with carbon tetrachloride or with dimidium bromide. A comparative survey was made of tissue enzyme levels in normal rats, cattle and sheep, together with a comparison of the various methods for transaminase assay.

Further investigations have been made into the natural blood groups of sheep, with particular reference to the characteristics of the blood of lambs. In addition, the life span of sheep red cells has been studied.

A.R.C. UNIT OF EMBRYOLOGY

Department of Zoology, University College of North Wales, Bangor, Caerns.

Honorary Director: Professor F. W. Rogers Brambell, B.A., D.Sc., F.R.S.

(Professor of Zoology, University College of North Wales)

Senior Scientific Staff:

W. A. Hemmings, B.A.

R. Halliday, B.Sc., Ph.D.

The principal interest of the Unit has been the immunological relations of mother and young in mammals and the way in which maternal proteins are transmitted to the young animal either before or after birth. Such maternal proteins include antibodies on which the passive immunity of the young animal depends.

On the 31st March, 1960, the scientific and experimental staff of the Unit numbered four.

CURRENT WORK

In the rabbit transfer of maternal protein (such as γ -globulin) takes place before birth, through the foetal yolk-sac membrane. The study of the mechanisms by which this occurs is continuing. Digestion of γ -globulin with pepsin or papain breaks down the molecules to smaller fragments; and if these fragments are labelled with radioactive iodine (I^{131}) their rates of passing through the membrane can be compared with that of similarly labelled whole γ -globulin. It has been found that whereas one fragment (III) is transmitted almost as readily as the whole γ -globulin, the other fragments (I and II) are transmitted much less readily. Further work continues on pepsin digested fragments and on a comparison of the transmission of the different fractions of normal maternal serum proteins.

The transmission of various antibodies and isotopically labelled serum protein fractions across the gut of the young rat has been studied. Work on serum cholinesterase and its origin in the young rat has been continued and shows that this enzyme is synthesised by the young animal, not passively transmitted from the mother.

The syndrome of experimental haemolytic disease in the young mouse produced by antileucocyte-platelet serum has been studied and compared with that produced by anti-red-cell serum. The differences between the two are clear cut. Further work is in progress on the relations of maternal leucocytes to the conceptus.

The ultracentrifuge and electrophoresis apparatus provided by a grant from the Rockefeller Foundation are in service and have greatly extended the experimental facilities of the Unit. A Rockefeller Foundation Research Fellow has been working in conjunction with the Unit during the year, as have members of the College staff and research students. Various problems associated with the early development and implantation of the mammalian blastocyst are being studied, as are also the immunological reactions of lower vertebrates.

A.R.C. UNIT OF MICROBIOLOGY
Department of Microbiology, The University of Sheffield

Honorary Director: Professor S. R. Elsdon, B.A., PH.D.
(Professor of Microbiology, Sheffield University)

Senior Scientific Staff:

J. L. Peel, B.A., PH.D.

D. S. Hoare, M.Sc., PH.D., A.R.I.C.

The work of the Unit is concerned with the study of the physiology and biochemistry of micro-organisms. During the year under review three main lines of work have been pursued: the metabolism of photosynthetic bacteria; the metabolism of rumen micro-organisms; the physiology of microbial growth. At 31st March, 1960, the scientific staff numbered two.

Experiments performed during the past year have confirmed and extended our earlier findings that illuminated suspensions of *Rhodospirillum rubrum* assimilate propionate *via* succinate, fumarate and malate. Thus, when suspensions of cells were incubated for short periods (5–240 seconds) with propionate and radioactive carbon dioxide ($^{14}\text{CO}_2$), succinate, fumarate, malate, aspartate and alanine formed were labelled exclusively in the carboxyl group. Cell-free extracts of *Rhodospirillum rubrum* and *Rhodopseudomonas capsulatus* have been prepared which, in the presence of propionyl co-enzyme A, adenosine triphosphate and $^{14}\text{CO}_2$, rapidly synthesise labelled succinic acid. Small amounts of labelled methyl malonate were also produced. The carboxylation of propionyl co-enzyme A is inhibited by avidin and this inhibition is reversed by biotin. These experiments show that the pathway of propionate assimilation in *R. rubrum* resembles that found in animal tissues.

A new method for the assay of the pyruvic dehydrogenase has been developed and is being used to follow the purification of the pyruvic dehydrogenase of the rumen organism LC. The enzyme is incubated in a mixture containing pyruvate, a catalytic amount of co-enzyme A, a redox dye, 2:6-dichlorophenol indophenol and excess of both oxaloacetate and condensing enzyme. The function of these last two components is to regenerate co-enzyme A from the acetyl co-enzyme A produced. Under these conditions the rate of reduction of the dye is proportional to the amount of pyruvic dehydrogenase. If excess pyruvic dehydrogenase is used then the rate of dye reduction becomes proportional to either the co-enzyme A or the condensing enzyme, whichever is made rate-limiting, and the system can thus be used to assay either the condensing enzyme or co-enzyme A.

An investigation of the growth and metabolism of *Selenomonas ruminantium*, an organism present in the bovine rumen, has been started.

The continuous-culture apparatus developed by the Unit has been used to study the properties of bacteria grown under defined conditions. It has been found that, when the nitrogen source (ammonium chloride) was made the factor limiting growth, the growth rate of the organism—which can be varied over a wide range—exercises a considerable effect on both the composition and the physiological properties of the organism.

DAIRYING

NATIONAL INSTITUTE FOR RESEARCH IN DAIRYING

Shinfield, Reading, Berks.

Director: Professor R. G. Baskett, O.B.E., M.Sc., F.R.I.C.

DAIRY HUSBANDRY

Head of Department: A. S. Foot, M.Sc.

R. Braude, D.Sc., Ph.D., Dip.Agr.

P. A. Clough, B.Sc.

F. H. Dodd, B.Sc., Ph.D.

C. Line, B.Sc.

K. G. Mitchell, B.Sc., Ph.D., N.D.A.

J. C. Murdoch, B.Sc., Ph.D.

FEEDING AND METABOLISM

Head of Department: C. C. Balch,
B.Sc., Ph.D.

W. H. Broster, B.Sc., Ph.D.

R. C. Campling, M.Sc.

J. H. B. Roy, M.A., Ph.D., Dip.Agr.

K. W. G. Shillam, B.Sc.

PHYSIOLOGY

Head of Department: S. J. Folley,
D.Sc., Ph.D., F.R.S.

P. Andrews, B.Sc., Ph.D.

G. K. Benson, B.Sc., Ph.D.

A. T. Cowie, D.Sc., Ph.D., M.R.C.V.S.

H. Gutfreund, Ph.D.

G. S. Pope, B.Sc., D.Phil., A.R.I.C.

J. S. Tindal, B.Sc., Ph.D.

RADIOBIOCHEMISTRY

Head of Department: R. F. Glascock,
B.Sc., Ph.D.

R. W. Smith, B.Sc.

BACTERIOLOGY

Head of Department: W. A. Cuthbert,
M.Sc.

Miss C. M. Cousins, B.Sc.

J. G. Franklin, B.Sc., Ph.D.

Miss E. I. Garvie, B.Sc., Ph.D., N.D.D.

D. J. Jayne-Williams, M.Sc., Ph.D.

M. Lev, B.Sc., Ph.D.

F. K. Neave, B.S.A.

B. Reiter, Ing.Agr.

Miss M. E. Sharpe, B.Sc., Ph.D.

CHEMICAL MICROBIOLOGY

Head of Department: N. J. Berridge,
D.Sc., Ph.D.

G. C. Cheesman, B.Sc., Ph.D., Dip.Bact.

L. A. Mabbitt, B.Sc., Ph.D.

CHEMISTRY

Head of Department: S. J. Rowland,
B.Sc., Ph.D., F.R.I.C.

R. Aschaffenburg, Ph.D.

I. H. Bath, B.Sc., B.Agr., Ph.D., A.R.I.C.

R. L. J. Lyster, M.A., Ph.D.

J. A. F. Rook, B.Sc., Ph.D., F.R.I.C.

R. H. Smith, B.Sc., Ph.D.

PHYSICS

Head of Department: G. W. Scott Blair,
M.A., D.Sc., Ph.D., F.R.I.C., F.Inst.P.

F. A. Glover, B.Sc., A.Inst.P.

J. D. S. Goulden, B.Sc., Ph.D.

L. W. Phipps, B.Sc., A.R.C.S., A.Inst.P.

J. H. Prentice, B.Sc., A.Inst.P.

ENGINEERING

Head of Department: H. S. Hall, B.Sc.

R. T. Budd, B.Sc.

H. Burton, B.Eng., M.Sc., A.M.I.E.E.

J. Hutchinson, B.Sc., A.Mech.E.

S. F. Suffolk, B.Sc.

C. C. Thiel, B.Sc., Ph.D.

NUTRITION

Head of Department: S. K. Kon,
D.Sc., Ph.D., F.R.I.C.

Miss M. E. Coates (Mrs. Goodwin),
Ph.D., F.P.S.

J. E. Ford, B.Sc., Ph.D.

Miss M. E. Gregory, M.Sc., Ph.D., A.R.I.C.

Miss K. M. Henry, D.Sc., Ph.D.,
A.R.C.Sci., F.R.I.C.

J. H. Moore, B.Sc., Ph.D., F.R.I.C.

J. W. G. Porter, M.A., Ph.D.

S. Y. Thompson, D.Sc., Ph.D.

Miss J. Toothill, B.Sc., Ph.D., A.R.I.C.

STATISTICS

Head of Section: C. P. Cox, M.A., F.S.S.

EXPERIMENTAL DAIRY

Miss H. R. Chapman, N.D.D.

LIAISON UNIT

W. G. Wearmouth, B.Sc., Ph.D.,
A.R.I.C., F.Inst.P., M.Inst.Pkg.

LIBRARY AND INFORMATION

J. A. Irvine, M.A.

B. F. Bone, B.A., A.L.A.

Secretary: H. F. Burgess, M.B.E., A.C.I.S.

The Institute was established in 1912 and is concerned with research associated with the wide field of milk production and milk utilisation. Much of the work is of a practical character and is designed to provide dairy farmers with information which will enable them to improve their methods for the economic production of good quality milk. Side by side with this work research of a more fundamental character is carried out in the hope of securing a better understanding of the physiological processes involved in milk production, the specific nutrient requirements of dairy cattle, and the physical, chemical and bacteriological significance of the changes involved in the processing of milk and its products.

The Commonwealth Bureau of Dairy Science and Technology is located at the Institute.

Dr. A. T. R. Mattick retired in September, 1959, after having been a member of the staff of the Institute for forty years. He was Acting Director from October, 1958, until July, 1959.

At 31st March, 1960, the scientific and experimental staff at the Institute numbered one hundred and three.

CURRENT WORK

The results of research work at the Institute are published in the Institute's own annual report and the following are but brief references to some aspects of the work which is being undertaken.

Physiology. An interesting line of research has been a study of the effects of removal of the pituitary gland (hypophysectomy) on lactation and the nature of the anterior-pituitary hormones necessary to maintain milk secretion after this operation. Experiments on the rat indicated that the lactogenic hormone, prolactin, together with corticotrophin (ACTH) are important for the maintenance of lactation after hypophysectomy. Studies have also been made on the effect of hypophysectomy on the pregnant and lactating goat. The operation is quickly followed by abortion at all stages of pregnancy and no lactation ensues; on the other hand, in a limited series of goats so far subjected to section of the pituitary stalk, abortion, should it occur, is somewhat delayed and is followed by milk secretion. Replacement up to about 50 per cent of the pre-operative yield has been achieved by administering a sextet of hormones, of which prolactin and somatotrophin seem to be the most important.

Studies on the biochemistry of lactation have been devoted to the biosynthesis of protein and amino acid metabolism. All steps shown to be involved in the incorporation of amino acids into protein molecules have been demonstrated in the mammary gland. Studies are being made of enzymes which activate amino acids and of the control of metabolism and energy production by mammary gland mitochondria.

Nutrition. Between January, 1958, and April, 1960, a survey was done, on the lines of a similar survey in 1943-44, of the vitamin A and carotene content of bulk milk from large depots throughout Great Britain. The annual mean for 1959-60 was sensibly the same as 15 years ago, but the values were higher in 1958-59, probably because the high rainfall favoured the growth of grass. There was no evidence that any change in farming practices during 15 years had by itself any effect on the carotene and vitamin A content of bulk milk.

Additional tests of tocopherols and vitamin D in the recent survey showed no differences between the values for the two years. The values for tocopherol were higher in the south than in the north. Values for vitamin D on the other hand were higher in the north than the south.

Joint work with the Department of Dairying, Reading University, showed that treatment with 0.05 per cent hydrogen peroxide followed by removal of the excess of peroxide with catalase improved the keeping quality of milk with a high bacterial count. No adverse effect was found on the B vitamins, vitamin A, or on the biological value of the proteins of the milk.

Dairy Husbandry. The milk yields of cows fed large quantities of silage increased when the concentrate portion of their ration contained protein in excess of that demanded by the feeding standards.

An experiment is being carried out to find out whether between-herd differences in the solids-not-fat content of milk are mainly due to genetic or environmental factors.

The improved growth rate and food conversion of growing pigs given diets supplemented with 0.1 per cent copper sulphate has been confirmed. The response appears to be related to the amount of soluble copper in the gut, but whether the site of action is in the body itself, or in the gut or both, is, as yet, unknown.

Chemistry. The lactose and potassium contents of the milk of heifers free from mastitis have been shown to be genetically-determined characteristics which may provide a basis for distinguishing between animals producing milk of low solids-not-fat content from genetic causes and those producing it from nutritional causes.

In studies of the various carbohydrates of herbage, it was found that cows digested cellulose and hemicellulose to the same extent, and when ^{14}C -labelled cellulose and hemicellulose were fermented by rumen micro-organisms *in vitro*, they gave rise to acetic and propionic acids in the ratios of 1.7/1 and 2.4/1 respectively.

Bacteriology. An artificial rumen has been developed which will partially simulate conditions in the bovine rumen for several weeks. It promises to be a useful experimental tool in bridging the gap between *in vitro* and *in vivo* studies of the microbiology of the bovine rumen.

The promise shown by circulation cleaning of a pipeline recorder plant has not been maintained. On occasions high bacterial counts have developed and there has been some deterioration in milk keeping quality.

No advantages have been gained over ordinary pasteurised milk by filling cold UHT sterilised milk into bottles and cartons. Some improvement in keeping quality was obtained by filling the milk hot into Crown cork bottles, but the development of aseptic filling is required before the advantages of the process can be fully utilised.

Chemical Microbiology. A study of the action of crystalline rennin on a casein fraction rich in the sensitive component is in progress.

A survey of the micro-flora of milk products by means of paper chromatography and allied techniques has been started in collaboration with the Bacteriology department. This project is sponsored by the U.S. Counterpart authorities.

A device for the continuous mechanical production of cheese curd has been developed and approximately 40 cheese have been made during the year. Despite the small scale of working (2 lb. of curd per hour), the results are encouraging. Operations on a tenfold larger scale will be undertaken as soon as possible and an attempt will be made to link the larger machine with the continuous cheddaring device. Patents have been assigned to the National Research Development Corporation.

Engineering. The cheesemaking industry has shown great interest in the process developed at the Institute for the continuous cheddaring of cheese curd and commercial development is now proceeding.

Experimental equipment for sterilising glass milk bottles and aseptic filling has been developed, and experiments are now in progress. An aseptic dispenser for UHT milk in tea-vending machines has been successful.

Two identical 3-unit pipeline milking machines have been designed and installed in a milking parlour at the Institute for experimental work on circulation cleaning material and techniques.

Facilities for handling milk in quantity have been improved to meet the growing volume of testing work required by manufacturers.

Feeding and Metabolism. In an attempt to determine the factors controlling the appetite of cows for roughages, the importance of physical factors such as rumen fill, the rate of emptying of the rumen and the rate of digestion in the rumen are being investigated in fistulated cows.

The infusion of large amounts of volatile fatty acids through the rumen fistula has now shown that the individual acids have both specific and general effects on milk yield and composition and probably on growth and fattening. This explains many of the changes in milk composition which follow changes in diet.

Preliminary studies suggest that although the early introduction of certain solid foods to calves may hasten rumen development, this has little effect on the subsequent ability of the calf to digest solid foods.

Physics. A rapid spectroturbimetric method for the determination of the mean fat globule diameter of homogenised emulsions has been devised and is being used in a study of the physical mechanism of the homogenisation process.

For milk, a simple mathematical relationship has been found between the fat globule diameter and the homogenisation pressure. A further development has led to a rapid method for the determination of both the fat content and the mean fat globule size in homogenised ice-cream mixes.

In the dairy, a number of tests for curd consistency have been brought into line with modern practice and a new test, involving measurements of electrical resistance, has been devised.

The kinetics of the action of rennet on milk casein have been studied by viscometric techniques and a new type of rolling sphere viscometer has been developed.

Radiobiochemistry. Of the radioactivity found in reproductive organs of ewes given physiological doses of tritium-labelled hexoestrol, 70 per cent has been identified as unchanged hexoestrol and the remainder as conjugated hexoestrol. Studies on the transport of intravenously injected hexoestrol show

that about 65 per cent diffuses out of the circulation within 15 sec. of the injection.

In continuing studies on the fate of hexoestrol in soil, it has been found that, although the level of radioactivity in soil dressed with labelled hexoestrol remains virtually constant for four months, only 8 per cent of it then remains chemically unchanged.

A published method for the fractionation of blood lipids has been rigorously tested on model mixtures of labelled components and found satisfactory for application to biological work.

HANNAH DAIRY RESEARCH INSTITUTE

Kirkhill, Ayr

Director: J. A. B. Smith, C.B.E., D.SC., PH.D., F.R.I.C., F.R.S.E.

BACTERIOLOGY

Head of Department:
Constance Higginbottom,
M.SC., PH.D., DIP.BACT.

BIOCHEMISTRY

Head of Department: E. C. Owen,
B.A., D.SC., PH.D.
W. Manson, B.SC., PH.D.

GRASS AND DAIRY HUSBANDRY

Head of Department: M. E. Castle,
B.SC., PH.D., N.D.A., N.D.D.
D. Reid, B.SC., PH.D., M.S.

NUTRITION

Head of Department: K. L. Blaxter,
D.SC., PH.D., N.D.A.
D. G. Armstrong, M.SC., PH.D., F.R.I.C.

Secretary: Miss M. M. Hughes

PATHOLOGY

Head of Department: P. S. Blackburn,
PH.D., M.R.C.V.S.

PHYSIOLOGY

Head of Department: J. D. Findlay,
B.SC., PH.D.
W. Bianca, DIPL.ING.AGR., DR.SC.TECH.
J. A. McLean, B.SC.
D. L. Ingram, B.SC., PH.D.
G. C. Whittow, B.SC., PH.D.

TECHNICAL CHEMISTRY

Head of Department: R. Waite,
M.SC., PH.D., A.R.I.C.
J. C. D. White, B.SC., PH.D.
D. T. Davies, B.SC., PH.D.

Librarian: Miss E. T. Davidson

The scientific and experimental officer staff of the Institute at 31st March, 1960, numbered thirty three.

The main object of the Institute's work is to study a wide variety of biological problems related to the production of milk and a number of technical problems associated with the handling of milk both before and after it leaves the farm. The biological problems include those arising from the production of grass and home-grown feeding stuffs, the nutrition of dairy cattle at all stages of growth and development, energy metabolism in ruminants, milk composition and factors that affect it, the influence of climate on the physiology of cattle, and the eradication and control of mastitis. The technical problems include those associated with the chemical and bacteriological examination of milk and milk products, the proteins and vitamins of milk and the keeping quality and other properties of dried milk.

CURRENT WORK

Grass and Dairy Husbandry. The main object of the research work done under this heading is to study and establish methods by which an optimum yield of milk of good quality can be attained on the Institute's farm with minimum reliance on imported feeding stuffs. This involves much detailed work of a long-term nature on the management of grassland and on the conservation and utilisation of grass and grassland products. The work on grass production is done first in several series of well-controlled plot experiments, and then later the more promising results are applied on a farm scale. In summer, grazing experiments are done to determine the most efficient ways of managing pasture both for grazing and for conservation purposes, and in winter when the cows are housed research is done to determine the extent to which grassland products such as hay and silage can replace purchased feeds without deleteriously affecting the yield or quality of the milk. Every year more knowledge is being gained on these various topics, and by applying this knowledge and experience the productivity and profitability of the Institute farm of 134 acres is gradually being increased. For example, in the year which ended on 31st March, 1960, the farm produced just over 43,000 gallons of milk, 2,000 gallons more than in the previous year. The milk yield per cow in herd was 854 gallons compared with 819 gallons the year before, and the corresponding figures for milk yield per acre in the two years were 330 and 299 gallons. In the year under review 20 tons of feeding stuffs were purchased but 30 tons of feeding stuffs produced on the farm were sold, making a net sale of 10 tons. The value of the total output of the farm was about £55 per acre.

In one series of plot experiments the effect of irrigation at various levels on the yields of herbage is being studied with particular reference to the interaction of fertiliser nitrogen with the clover constituent of the herbage. In the summer of 1959, which was a relatively dry season, there was an increase of almost 2 cwt. of dry matter per acre per inch of water applied. Irrigation had no measurable effect on the depression of clover by nitrogen. This work is continuing in the current year. In another series of plots a comparison is being made between the effects of applying liquid manure from the byre to grassland and the effects of applying similar amounts of nitrogen and potassium in the form of chemical fertilisers. The yields, quality and botanical composition of the resulting herbage are being studied. The effect of applying the liquid manure on a series of different dates during the winter on the yield and composition of the herbage obtained during the subsequent growing season has also been investigated. At the first cut in May, applications of liquid manure which had been made in November, December, February and March all led to increased yields compared with the controls which received no manure, but at the second cut in July the yields from the treated herbage did not exceed those of the controls. These preliminary results are promising, and if they are confirmed by further work, purchases of fertilisers for the farm may well be appreciably reduced in the next few years.

In a grazing experiment to determine the value of feeding supplementary concentrates when the cows are on well-managed good quality pasture, it was found that under the conditions of this experiment the feeding of the supplementary concentrates was quite uneconomic. To produce one extra gallon of milk worth 2s. 6d. required 42 lb. concentrates costing 10s. It was clear that

with cows giving 4 gallons per day there was no justification for feeding concentrates provided the cows were on pasture of good quality.

Work has continued on the value of ten different strains of lucerne when grown in this south-western area of Scotland. The experience which has now accumulated shows that the utilisation of lucerne presents problems which make it seem unlikely that it will become an important crop in this district.

Nutrition. A further respiration chamber has been constructed which means that there are now available five chambers for sheep and one which accommodates a cow or full grown steer. This equipment is being used to study the energy requirements of ruminants for growth, maintenance, pregnancy and lactation. The object is to gain as much information as possible on the energy metabolism of ruminants and of the ability of different feeding stuffs to meet these requirements. Many aspects of the subject are being studied. One series of experiments, for example, is concerned with the energy cost of the muscular work involved by the ruminant in walking and grazing, and a comparison is being made of food utilisation by ruminants during exercise with food utilisation when the animals are confined to stalls. This is an important problem since so far the small amount of information that is available has been obtained almost entirely with stall-fed animals. The results so far obtained have indicated that the cost of walking on level ground in the sheep is 0.5-0.8 kcal per kg. of body weight per meter of distance walked, which is similar to the corresponding value for man of about 0.51 kcal. In experiments on the subject of food utilisation during exercise it was found that the digestibility of the food energy and the net availability of the metabolisable energy of the food given for maintenance and for fat production were not affected by exercise.

Studies on the energy cost of fat synthesis in ruminants, when protein serves as a source of energy for this process, have been started. This is the situation which occurs when an animal is given food containing more protein than it requires. It occurs in cattle on grass and when cattle are fattened on rations containing high-quality silages and certain other home-grown fodders. As part of this investigation a comparison of the metabolism of sheep is being made when they are given protein via the rumen and protein via the abomasum to determine the part played by changes that take place in protein within the rumen.

A study is being made also of the factors that affect appetite in ruminants, one object being to establish the best way of measuring voluntary food intake in sheep and cattle.

In addition to these extensive energy metabolism studies a field trial involving 160 beef calves has been made, in collaboration with Veterinary Investigation Officers in the north of Scotland, to determine to what extent selenium will prevent muscular dystrophy. The trial involved 20 farms. On each farm some calves acted as controls, some received vitamin E and some received selenium. Both selenium and vitamin E were effective in very greatly reducing the incidence of muscular dystrophy.

Physiology. The new climatic laboratory which was opened in 1959 was fully in use for a part of the period now under review. The various experiments which have been done in it so far have been planned to study the nature of the central and peripheral control of body temperature in cattle, the part played

by the Tunica dartos muscle as a temperature regulating system, the acid-base balance of the blood of cattle during thermally induced hyperpnoea and methods of measuring the evaporation of moisture from the skin. Preliminary studies have been made also to gain information on blood flow in the extremities of cattle exposed to various temperatures in order to obtain insight into the mechanisms of vasomotor control and peripheral heat loss.

The morphology and functional ability of the sweat glands of cattle have been studied in detail. The results have indicated that if the sweat glands are functional they cannot be apocrine and that they must either function eccrinely or lose moisture by diffusion through the glandular epithelial wall. This work is continuing.

Milk and milk products. Much work has been done at the Hannah Institute on the cell count of milk and the incidence of sub-clinical mastitis. Since that form of mastitis may well affect milk composition, a study has now been made of the relationship between the cell count of milk and its non-fatty solids content. In one of the experiments, milk was taken from each quarter of 100 cows in two herds. Each quarter sample was taken in three portions, (a) the first 3-4 ml., (b) the next 10 ml. and (c) a representative 200 ml. sample of all the milk obtained from the quarter by milking into a quarter-milking bucket. Negative correlations were obtained between the total cell counts of all three portions of the quarter samples and the non-fatty solids content of the 200 ml. representative sample of the milk. Yield of milk was negatively correlated with cell count and positively with non-fatty solids content.

In the manufacture and storage of milk products such as evaporated and sweetened evaporated milks, problems sometimes arise from the instability of the protein complex of the milk. A long-term basic study is being made of this protein instability and the factors which affect it, such as the proportions of the ionised, soluble and colloidal fractions of the mineral elements present in the milk and the heat treatment to which it is subjected.

Research has continued also on the vitamins of milk, on the chemistry of casein and on factors that affect the keeping quality and certain other properties of dried milk.

The bacteriology of milk and milk products. Work on the coliform test has continued, and a study has been started of the effect of introducing bulk milk collection to a number of farms on the bacterial flora of the milk they produce. Another aspect of the Institute's bacteriological work has involved research on the changes that occur in milk during sterilisation in its properties as a growth medium for spore-forming bacilli. The results of this last investigation have now been published.

Disease. Research on the eradication and control of mastitis has continued, and a further study has been made of the incidence of ketosis in the dairy herd.

The Institute publishes a printed report every three years. The current issue covers the three-year period which ended on 31st March, 1959. It gives an account of the work done in each of the seven departments of the Institute and includes a list of the papers published in that period. In April, 1960, a *Guide to the Institute Farm* was issued. It provides a detailed description of the farm and of the many experiments for which the farm supplies the necessary facilities. Copies of these publications may be obtained on request.

POULTRY

A.R.C. POULTRY RESEARCH CENTRE

King's Buildings, West Mains Road, Edinburgh, 9

Director: A. W. Greenwood, C.B.E., D.S.C., PH.D., F.R.S.E.

Assistant Director: J. H. Sang, B.S.C., PH.D., F.R.S.E.

GENETICS

J. H. Sang, B.S.C., PH.D., F.R.S.E.

Miss J. S. S. Blyth, B.S.C., PH.D.

A. G. Cock, M.A.

G. Tebb, B.S.C., PH.D.

C. F. Pun, M.S.C., PH.D.

BIOCHEMISTRY

D. J. Bell, M.A., SC.D., PH.D., F.R.S.E.

W. M. McIndoe, B.S.C., PH.D.

ANIMAL BEHAVIOUR

D. G. M. Wood-Gush, B.S.C., PH.D.

P. E. Guiton, B.A., D.PHIL.

Secretary: A. B. Totty, B.A.

NUTRITION

W. Bolton, D.S.C., F.R.I.C., F.R.S.E.

PHYSIOLOGY

A. B. Gilbert, B.S.C.

P. E. Lake, B.S.C., PH.D.

P. D. Sturkie, M.S.C., PH.D., F.R.S.E.

PATHOLOGY

W. G. Siller, B.S.C., D.VET.MED., M.R.C.V.S.

P. A. L. Wight, B.S.C., PH.D., M.R.C.V.S.,
D.V.S.M.

Librarian: J. B. Coltherd, M.A.

The work of the Poultry Research Centre is concerned with all aspects of the biology of the fowl, and particularly with those of primary relevance to the Poultry industry.

The scientific and technical staff at 31st March, 1960, numbered twenty-two.

CURRENT WORK

Experiments are continuing on the subjects noted in previous reports; namely, hybrid vigour in the fowl, the blood chemistry of birds with cage layer fatigue and other metabolic abnormalities, the development of diluents to be employed for sperm storage and artificial insemination, the aetiology of nephritis, and the manifold effects of ageing. Only selected new or completed projects are noted below.

Genetics. The increasing use of special strains or crosses for meat production (broilers) has become a major concern of the industry. Scientific information on those complex problems of growth and conformation which will permit the efficient development of broiler strains is far from adequate; fundamental studies have therefore been started on selection for different characteristics using a base population formed by crossing four breeds. Two of the lines are being selected in opposite directions for conformation, the criteria being long or short shanks in relation to body weight at ten weeks. The initial response has been rapid, the realised heritability exceeding 50 per cent for the first two generations. The physiological genetics of conformation is also being examined in this material by measurement of the ways in which differences arise during growth and how they are expressed in the two sexes. The growth of the shank

relative to body weight (on appropriate scales) is nearly constant from two to ten weeks and differences of this relative growth rate account for about half the variability of the population. While this relative growth difference is genetically controlled it has not yet contributed to the response to selection which has been mainly in differences determined during the first two weeks. Two further lines are being selected for high and low body weight at ten weeks, and a fifth line is being selected for heavy females and short shanked males. When clear differences have been established, the five selected lines will be combined in crosses to test the behaviour of their attributes in hybrids.

The biochemical and physiological characteristics of the Centre's selected lines of Brown Leghorns are also being studied in a search for genetic differences which may affect production traits. It has been found that different protein patterns can be demonstrated in egg white by electrophoresis and nine different albumen types have been identified so far. Preliminary data suggest that these are determined by the segregation of three sets of mendelian genes. All but one of the eight selected lines are heterogeneous for these albumen characteristics.

Nutrition. Attention is currently being devoted almost exclusively to the nutrition of the young chick, and to the effects of dietary additives on efficiency of digestion. Supplemental fat in the diet depresses the digestibility of carbohydrates; the degree of depression increasing with the amount of fat added. Non-ionic or anionic detergents do not affect the digestibility of fats, but addition of cationic detergents lowers the percentage of fat digested. Inconsistent results have been obtained from enzyme supplementation; in two experiments it resulted in an increase of the amount of carbohydrate digested, in a third it had no effect. The efficiency with which the digested food is utilised by the growing chick is being investigated.

Biochemistry. Chemical examination of cock seminal plasma, as part of artificial insemination diluent studies, revealed an unexpectedly high acid phosphatase activity. Examination of the seminal plasma of a number of mammals showed that the levels of acid and alkaline phosphatases in them are related to the size of their prostate glands (acid phosphatase-secretory) and of their seminal vesicles (alkaline phosphatase-secretory). Histochemical studies of the reproductive tract of the cock has led to the determination of the main sites of secretion of the two enzymes.

The composition of egg yolks may be expected to differ for genetic reasons and under different physiological states. However, examination of selected lines which produce yolks of different sizes has revealed no significant difference in cholesterol content per unit weight of yolk. Study of yolk proteins, their origin and transport to the ovary has been extended by the demonstration, using modern techniques, that yolk is a much more complex mixture of proteins than hitherto suspected. A solvent has been developed which will facilitate the further examination of these protein mixtures and which should permit examination of detailed genetic and physiologically induced changes.

Physiology. Hens have a smaller blood volume than cocks (when corrected for weight differences) and this divergence first appears when the ovaries start to mature. How far this is due to increased levels of oestrogen at this time is not clear and experiments have been initiated into the effects of this hormone on the characteristics of blood. Oestrogen injection inhibits red cell formation

and increases the red cell sedimentation rate by affecting the characteristics of the plasma. Thyroxin injection reduces this oestrogen effect. However, total blood volume is maintained at a relatively constant level per unit body weight by mechanisms regulating plasma and blood cell volumes. Not all strains have the same blood volume or red cell content per unit body weight, and the elementary genetics of these differences is being studied in two of the Centre's selected lines and in hybrids between them.

Pathology. Little is known of the neuropathology of the fowl and a programme has been started in this field. Attention is being paid in the first place to spontaneous fowl paralysis, to the detailed histological and sub-microscopic lesions found, and to the formation of antibodies, if any, in this condition. Tests for the transmissibility of the disease and for the reproduction of similar nerve lesions by experimental techniques are also being carried through.

Moderate atherosclerosis occurs frequently in older, apparently healthy birds. Very severe and widespread atherosclerotic lesions have been produced experimentally in birds fed exclusively on eggs. The distribution of these lesions appeared to differ from that of cholesterol-induced atherosclerosis. Most interesting is the occurrence of aortic ruptures in a number of birds of this group. Whilst spontaneous rupture of the abdominal aorta occurs in human atherosclerosis subjects and in turkeys it has not previously been reported in fowls, not even in experimentally induced atherosclerosis.

The morphological study of ventricular septal defects in fowls has been reported previously. The embryological development of these defects is being investigated by micro-dissection in co-operation with two Czechoslovakian workers. In the defective embryonic hearts an additional cushion developed in the truncus arteriosus. By causing a temporary stenosis, this transient "aortic" cushion may be responsible for the development of the septal defect.

Behaviour. Work on the circumstances affecting the sexual behaviour of the cock has been extended to the influences acting during early development. For a short period during the first week or two after hatching a bird may become "imprinted" on an object, animate or inanimate. Birds so imprinted on a member of a species other than their own are unwilling to mate with their own kind when mature, and such detrimental imprinting might occur in the routine rearing of chicks. Male chicks have been tested for this by imprinting them to inanimate objects and, although they show a preference for these subsequently, this eventually disappears. Experiments on the effects of imprinting to a human subject are not yet complete. The variability found in these tests suggests that it should be possible to select strains which are easily imprinted and strains which are not.

In an attempt to determine if it is possible to identify sexually vigorous birds at an early age, young cockerels have been given injections of male hormone and their precocious sexual vigour assessed. This will be related to their activity as adults. Birds of strains already selected for high or low sex drive will also be used to extend these studies.

General. In view of the debatable carcinogenic activity of certain natural products, and synthetic additives (oestrogens) to feeding stuffs, the following progress report of experiments which have been conducted over an extended period is given.

Groups of male and female chickens have been maintained on a normal diet supplemented with dienoestrol diacetate from hatching and subsequently for more than three years. Death rate was not unduly high and only two females have so far developed tumours—an incidence within the range that might be expected from normally fed birds.

It has been reported that if eggs formed an appreciable proportion of the diet of laboratory animals (including chickens) the tumour incidence was unduly high. From an experiment in which boiled eggs were the sole dietary constituent fed to a small group of fowls of the Edinburgh flock from hatching and over a period of $2\frac{1}{2}$ years, no deaths in which tumours were involved have occurred to date.

HOUGHTON POULTRY RESEARCH STATION

Houghton, Huntingdon

Director: R. F. Gordon, D.SC., M.R.C.V.S.

PARASITOLOGY

C. Horton-Smith, PH.D., D.I.C.

*Mrs. M. Elaine Rose, PH.D., M.R.C.V.S.

VIROLOGY AND PATHOLOGY

J. S. Garside, PH.D., M.R.C.V.S., D.V.S.M.

P. M. Biggs, B.SC., PH.D., M.R.C.V.S.

BACTERIOLOGY

E. G. Harry, M.SC., B.PHARM., PH.C.

NUTRITION AND BIOCHEMISTRY

L. G. Chubb, M.SC., A.R.I.C.

PHYSIOLOGY

*J. Beattie, M.D., D.SC.

CLINICAL AND DIAGNOSIS

C. C. Wannop, M.R.C.V.S.

W. M. Goodchild, M.SC., M.R.C.V.S.

HUSBANDRY

Miss D. M. Cooper, B.SC.(AGRIC.)

Secretary: P. J. Lane, A.C.I.S.

* Attached worker.

The new laboratory wing was formally opened by Lord Rank on 13th May, 1959.

In November the Station had the misfortune to experience an outbreak of Newcastle disease which necessitated the slaughter of both production and experimental flocks in accordance with the Fowl Pest Order. This outbreak interfered to a considerable extent with the work of the Station during the Spring of 1960. During the depopulation period the opportunity was taken to erect decontamination units, fences, etc., which should improve the security of the Station flocks against extraneous disease.

Part of the old laboratory block has been reconstructed as a hatchery unit and one wing is in course of being equipped as a physiology laboratory.

On the 31st March, 1960, the scientific and experimental staff of the Station numbered thirteen and there were three attached workers.

CURRENT WORK

In the main the research of this Station is directed towards the investigation and control of infectious and parasitic diseases in poultry, particularly those

arising from the continued trend towards intensive production, together with certain studies of problems in nutrition, physiology and husbandry bordering on the disease field. A diagnostic service is maintained with the purpose of keeping the Station in touch with the problems of the industry and providing material for research.

Bacteriology. When an inoculum of *Salmonella typhimurium* derived from a single colony, with an initial tolerance to chlortetracycline at 20 p.p.m., was administered to chicks receiving this antibiotic in the diet, there was a 10-fold increase in the resistance of the organism to the antibiotic reaching a level of 210 p.p.m. after four passages. In chicks receiving the antibiotic-supplemented diet, the antibiotic-resistant strains persisted for as long as 14 weeks without any decline in resistance. There was no evidence that an increase in resistance of *S. typhimurium* to chlortetracycline was accompanied by an increase in the virulence of the organism or that sensitive strains were less pathogenic than resistant ones. The antibiotic gave a measure of protection against artificial infection with *S. typhimurium*, the mortality rate in the antibiotic-fed chicks being approximately half that in the chicks not receiving the antibiotic. The design of the experiment and the use of phage-typed cultures, supported by *in vitro* tests, indicated that the resistant strains of *S. typhimurium* recovered from the antibiotic-fed chicks stemmed from the original sensitive strains used.

The incidence of *Salmonella* infections appears to be on the increase and although the commonest species isolated have been, as in the past, *S. typhimurium* and *S. thompson*, new species are continuously being isolated. During the last year the following were added to our list: *S. braenderup*, *S. orion*, *S. cubana*, *S. binza* and *S. chailey*.

Investigations have continued into the pathogenicity to the chick embryo of bacteria derived from the hen, and the origin of certain types of bacteria capable of growth at incubation temperature has been studied in relation to pens, individual females and the semen of individual males. The effect on embryonic mortality of soilage of the eggshell by faecal matter, has also been investigated, assessing separately the effect of mechanical blockage of the pores and bacterial penetration.

A simple method has been established which can be used in the field and by hatchery owners to estimate the formaldehyde concentration present in fumigation chambers and incubators. A leaflet outlining the technique and apparatus required can be obtained from the Station.

An examination has been made of strains of *Escherichia coli* from avian sources to determine initial resistance to certain antibiotics, ability to develop resistance when grown on sub-bacteriostatic levels of antibiotic, the degree of permanence of resistance acquired and the extent to which such changes are accompanied by other changes in biochemical behaviour and morphology.

Parasitology. The nature of the immunity acquired to caecal coccidiosis is being investigated by ligating one caecum of a coccidia-free chick, leaving one open caecum for infection by the mouth. The infection administered can be so adjusted that an immunity-stimulating infection can be produced in the open caecum. Challenge of the ligated caecum 14 days afterwards showed that a complete resistance to infection had developed in it, indicating some form of circulating antibody originating from the open infected caecum. These observa-

tions led to the start of an experiment designed to demonstrate circulating antibody by serological methods, using both precipitation reactions and electrophoretic procedures on serum proteins. Complete immunity from the challenge infection has been obtained in chickens and investigations of these chickens have shown that precipitating antibodies can be detected. The chickens remain resistant to re-infection when antibodies have apparently disappeared.

The antigenic relationships between different species of coccidia parasitising the fowl are also being investigated.

Work continues on the screening of various anti-coccidial agents both in caecal and intestinal coccidiosis of the fowl and turkey.

Virology. Work has started on the study of certain respiratory diseases of the fowl with a view to designing more rapid methods for their diagnosis and differentiation. The use of the gel diffusion precipitation test for this purpose is being investigated, together with tissue culture techniques and fluorescent microscopy.

Biochemistry. The study of the effect of tumour inhibiting compounds on certain transplantable lymphoid tumours has continued. A few folic-acid and purine antagenists increased the survival time of tumour-bearing chickens, but total mortality was not reduced.

Paper chromatography and paper electrophoresis have been utilised in studies of the effect of tumour on the host. Liver damage induced by R.P.L. tumour does not significantly alter the total amino nitrogen in the blood plasma and the plasma amino acid pattern of these birds is not markedly different from that of non-tumour-bearing controls. No significant changes occur in the total serum protein level of the tumour-bearing chickens although there is a reduction in albumen and a corresponding rise in globulin fractions.

Physiology. A study of the heat production and water output of the chick from day-old to the broiler marketing stage is in progress. The rate at which oxygen is used in the body tissues per unit of body weight is relatively slow during the latter stage of incubation. It rises rapidly before hatching and thereafter until the body weight is about 60 grams. At this stage the oxygen uptake and consumption is six times that on the 18th day of incubation. Thereafter the rate of oxygen consumption remains constant and the total oxygen consumption per day is directly proportional to the body weight of the chick. The mechanisms responsible for the accelerating rate of consumption are being studied and as yet there is no explanation as to why this acceleration of oxygen consumption ceases to operate at a particular body weight. It is of interest to note that it is at this critical time that the maximum mortality of chicks from non-specific causes occurs.

By observing the oxygen consumption of chicks after hatching it appears possible to differentiate between different strains of birds, this difference being obvious before the end of the first week after hatching. Such observations may be of practical value in predicting at an early stage the time at which any strain is likely to reach a given weight.

A study is being made of the amino acid content of fowl semen by paper chromatography. The results to date confirm those of other workers, and in addition several amino acids have been detected which have not previously been reported.

AGRICULTURAL ENGINEERING

NATIONAL INSTITUTE OF AGRICULTURAL ENGINEERING

Wrest Park, Silsoe, Bedfordshire

Director: W. H. Cashmore, C.B.E., B.A., N.D.A.

AGRICULTURAL MACHINERY TESTING

Head of Department: D. I. McLaren,
B.SC.(AGRIC.), N.D.A.

P. Hebblethwaite, M.S.,

B.SC.(AGRIC.), N.D.A.

R. D. Richardson, B.SC.(ENG.),

A.M.I.MECH.E.

FIELD INVESTIGATION

Head of Department: F. S. Mitchell,
B.SC.(AGRIC.)

R. E. Arnold, B.A.(AGRIC.)

G. Shepperson, B.SC., DIP.AGRIC.

GRAIN DRYING

J. Woodforde, M.I.E.E., A.M.I.MECH.E.

P. E. Berry, M.SC., A.M.I.MECH.E., A.F.R.A.E.S.

J. B. Holt, M.SC.

M. G. R. Warner, M.A., A.M.I.E.E.

GLASSHOUSE RESEARCH

Head of Department: L. G. Morris,
B.SC.(ENG.), A.F.R.A.E.S.

G. A. Carpenter, B.SC., DIP.CHEM.ENG.

J. V. Lake, B.SC., PH.D.

HORTICULTURAL ENGINEERING

Head of Department: F. V. Vanstone,
B.SC., PH.D., A.INST.P.

A. G. M. Bean, M.A.(ENG.), A.M.I.MECH.E.

J. B. Byass, M.A.

R. J. Courshee, B.SC.(ENG.)

J. S. Wolfe, B.A., B.SC.(ENG.)

INSTRUMENTATION DEPARTMENT

Head of Department: S. W. R. Cox,
B.SC., A.INST.P.

MECHANICAL ENGINEERING DEPARTMENT

Head of Department: H. J. Hamblin,
O.B.E., B.A.

P. H. Bailey, B.SC.(ENG.), A.K.C.

D. E. Howson, B.SC.

T. C. D. Manby, M.SC.(ENG.)

H. J. Nation, B.SC.(ENG.), A.M.I.MECH.E.

SOIL MECHANICS DEPARTMENT

Head of Department: J. C. Hawkins,
B.SC.(AGRIC.), N.D.A.

E. R. Fountaine, B.A., B.SC.

SURVEY DEPARTMENT

Head of Department: J. K. W. Slater,
M.A., M.SC.

Commonwealth Liaison Officer: N. M. Garrard, B.E.(MECH).

Secretary: J. W. Andrews, F.C.I.S.

Librarian: Miss J. A. Midgley

The work of the Institute is to carry out research and make investigations to provide basic data for the design and improvement of machinery, and also the establishment of new and improved farm techniques. In the course of the work some new machines are developed for agriculture and horticulture. A full account of the Institute's activities is given in an annual report which is published each Spring.

The Institute also operates a testing service covering all classes of tractors and implements. The scientific and experimental staff on 31st March, 1960, numbered one hundred and three.

CURRENT WORK

Farm Surveys. The main investigations have been a study of the incidence of damage to potatoes from the time of lifting in the field to delivery to the

retailer, and a survey of the contamination and incidence of damage in combined wheat.

Investigations. A three-year series of experiments was carried out to determine the precise effects of single and double mechanical thinning of sugar beet. The results showed that the use of a mechanical thinner to open out an initial braird of average thickness made the timing of subsequent hand-work less critical than with an unthinned crop. If these results are confirmed on a farm scale, down-the-row thinning could have wide applications, especially in years when the crop is likely to get ahead of the hoemen.

A continuation of a study of damage to grain during threshing has shown that, apart from moisture content, the shape and the state of the grain samples are important factors. For instance, grain with either a deep open crease, or grain with the endosperm offset to the vertical line of the crease, is more liable to break than grain of a more uniform shape. Flinty grains of a high nitrogen content are more liable to break than floury grains in any one group. There are indications that the relationship between dimensions of the concave and the diameter of the cylinder has a bearing on the optimum cylinder speed. This work might lead to an improvement in combine design.

RESEARCH AND DEVELOPMENT

Soil Physics. Work carried out in Britain on the action of simple tines working in normal field conditions has been repeated in the soil bins of the U.S.D.A., National Tillage Machinery Laboratory, Auburn, Alabama. The values determined under these controlled conditions have agreed very closely with the field results. Other research at Auburn in a glass-sided box has indicated that present theories about the pattern of the flow of soil round a moving tine need some modification.

In efforts to determine a cheaper alternative to tile drains, a rig has been evolved to form a stable tube from a ribbon of high density P.V.C. foil. A machine is being designed for field trials.

Grain. Research into the drying characteristics of cereals has included the rate of drying with different inlet air temperatures and air flows and the pattern of grain flow in the vicinity of internal air ducts.

A simple indirect air heater is being developed for use with grain and hay drying installations. The design incorporates existing proprietary components.

Horticulture. The primary purpose of the glasshouse investigation is to determine the accuracy of temperature control required for growing tomatoes in glasshouses. It is carried out in conjunction with Fairfield and Efford Experimental Horticulture Stations, and is co-ordinated with the wider programmes of the Glasshouse Crops Research Institute and the John Innes Institute.

Improvement in early yield has resulted from the use of higher night temperatures. Electronic controls for both heating and ventilation have been developed to enable research to proceed on daytime control. It has already been shown that the control of daylight air temperatures is improved by the use of automatic ventilation and a ventilation control device suitable for growers has been developed and installed in twelve glasshouses at the various experimental horticulture stations.

Experimental work has shown that CO_2 concentration is a factor in the control of ventilation, because at certain times the CO_2 concentration may be reduced below the optimum requirements for the plants.

Work on fruit spraying machinery has indicated that an expensive high pressure pump is not necessary. To assist the further development of fruit sprayers, and to obtain general background information, a commercial-scale spraying investigation is being carried out in the west of England.

Experiments on the automatic bed watering for cucumbers showed that even in the high sunshine summer of 1959, no benefits accrued from the use of shading. It seems likely that the need for shading arises from inadequate bed watering.

An investigation into the efficiency of installations used for the hot water treatment of bulbs for the control of eelworm showed that the recommended requirements were not met. Proposals have been made for modification of the equipment. It is considered that further laboratory work on the relation between temperature and time on the control of eelworm is necessary before a satisfactory solution can be obtained.

Apparatus and Equipment. In work for other research stations, the emphasis has moved to the design of equipment for harvesting experimental plots. A combine harvester with a 3-foot cut is being built for cereal plots; it is self-propelled and the operator rides on the machine. For herbage seed plots a tractor-mounted harvester has been fitted to the arms of a front-end loader. Other work includes the development of a small pea viner and the harvesting of hop plots in collaboration with the Hop Department of Wye College.

Overseas. In collaboration with the East African Testing Unit, tests of driers are being carried out in East Africa. As a result of a test on one pyrethrum drier, the throughput has been increased by 12 per cent and the fuel consumption reduced by 15 per cent. Grain drier tests are of particular interest because the results provide an opportunity for comparing drier performance at 6,000 feet, with U.K. results obtained at sea level. Other equipment tested includes small motorised cultivators and bush clearing machines.

Testing. The technique of measuring the rate of wear of an engine by monitoring the lubricating oil, when running with a radioactive piston ring, is being successfully applied to the measurement of the performance of tractor air cleaners, to which prepared dust is fed in different concentrations.

There is still a strong demand from manufacturers for implement tests and there is an increasing interest by manufacturers and other organisations in testing technique studies. It is becoming increasingly evident that the average performance of a machine on a farm is very different from the optimum performance under test conditions. This indicates lack of experience in operation and the need for more educational work.

NATIONAL INSTITUTE OF AGRICULTURAL ENGINEERING

SCOTTISH STATION

Howden, Mid Calder

Director: W. J. West, B.A., DIP.AGRIC.

Senior Scientific Staff:

D. P. Blight, B.SC., M.SC.(AG.ENG.), PH.D.

R. G. Clark, B.SC.(AGRIC.), M.SC.(AG.ENG.)

G. Gilfillan, B.SC.(ENG.), M.SC., A.R.T.C., A.M.I.MECH.E.

I. M. Robertson, B.SC., PH.D.

Secretary: D. Warne, F.C.C.S.

The scientific and experimental staff of the Station at 31st March, 1960, numbered twelve.

CURRENT WORK

A successful method was devised for the hydraulic control of the front furrow width of a mounted plough. To achieve this, modifications had to be made to the standard hydraulic systems of the tractors used.

The N.I.A.E. stone hoist, re-designed to give quicker lowering of the hook and a lift high enough to enable boulders to be loaded on to standard trailers, performed satisfactorily in extended trials.

Further treatments were carried out in the experiment to determine the nature and frequency of the mechanical treatments necessary to prevent bracken, that has been brought under control, from re-establishing itself.

A farm trailer was built around a German power-driven axle and will be used in an investigation of the problems of transport on steep hillsides and soft ground.

The investigation into the relationship between the size of turnip and swede seed and the efficiency of precision seeders was continued and extended. An electronic device was designed for counting the total number of seeds delivered by a seeder and to differentiate between single seeds and seeds dropped in groups of two or three. At present the device is only suitable for laboratory work but it will be developed further for field work. Further experiments were carried out to determine the effect on singling labour of using a mechanical thinner. The performance of the Station's thinner, with reciprocating cutter heads, was greatly improved by converting it from land-wheel to power take-off drive.

Bales of hay were built into various types of field rick and continuous records of their rates of drying obtained. Each rick contained 12-15 bales which were arranged to give good shedding of rain and as much aeration as possible.

A farmyard manure spreader was modified for use in "zero" grazing. A side-delivery conveyor, fitted to the rear, delivered fresh grass harvested by a flail-type forage harvester to feeding troughs. The maximum rate of delivery achieved was only about half of that required.

The rates of drying of various sized swaths of barley and wheat were determined. The investigation into the optimum working conditions for pick-up combine harvesters was extended to include three barley varieties, one oat and one wheat variety, three swathing machines and four combine harvesters. To assist with this work an air elutriator was developed for cleaning the large number of grain samples that had to be examined.

Sufficient progress was made in the construction of a new experimental grain-drying plant to enable checks to be made of the design performance. Building of the plant continued. Experiments were conducted with a bin specially built for an investigation into the effect of grain-bed shape on the passage of air at various speeds through different depths of grain.

An assessment was made of the damage done to Majestic potatoes by three methods of lifting on different soil types. The problem of separating potatoes from stones and clods by hand and by mechanical means was studied; of the mechanical methods tried the one in which an air blast was directed across a vibrating conveyor was considered to be worthy of further study. Methods of presenting the potato-stone-clod mixture to the pickers on a harvester were examined but attempts to develop, on a field scale, an improved laboratory method were not successful. The effects of different methods of cultivating potatoes and the effect of windrow harvesting on the amount of clods reaching the picking table of a harvester were investigated. Further development work was done on the Station's haulm puller.

An experimental spool-type potato sorter was used, with two varieties of different tuber shape, to determine the relationship between the efficiency of grading and the number of spool rollers on the grading deck.

A laboratory investigation was made of the fertiliser distributing mechanisms of various combined grain and fertiliser drills in an attempt to ascertain the reasons for the uneven development of cereal crops. The unevenness would appear to be due to the erratic discharge of the fertiliser into the coulter tubes.

Further information on the work described may be obtained from the Station's Annual Report which forms part of the Annual Report of the N.I.A.E.

FARM BUILDINGS

A.R.C. FARM BUILDINGS UNIT

Wrest Park Lodge, Silsoe, Bedfordshire

Honorary Director: W. H. Cashmore, C.B.E., B.A., N.D.A.

Head of Unit: J. K. W. Slater, M.A., M.Sc.

Senior Scientific Staff: C. N. Harvey, M.A., Q.A.L.A.S.

The unit has been established to serve the A.R.C. Farm Buildings Research Committee which was set up in 1957. Its main functions at present are the preparation of "A Bibliography of Farm Buildings Research" and a survey of existing farm buildings in Great Britain. In future it will be undertaking the design, supervision, analysis and writing up of the experiments under the Council's Experimental Farm Buildings Scheme.

On 31st March, 1960, the graduate staff numbered three in addition to the Head of the Unit, but assistance is given by the Survey Department of the N.I.A.E. on the farm buildings survey.

FOOD

DITTON LABORATORY

Larkfield, Maidstone, Kent

Director : R. G. Tomkins, M.A., PH.D., M.INST.R.

BIOCHEMISTRY

A. C. Hulme, D.SC., PH.D.
J. D. Jones, M.SC., D.PHIL., A.R.I.C.

ORGANIC CHEMISTRY

D. F. Meigh, B.SC., PH.D.

MYCOLOGY

K. L. Edney, B.SC., A.R.C.S.

ENGINEERING

G. Mann, A.M.I.MECH.E., A.M.I.MAR.E.

PLANT PHYSIOLOGY

Apples and Pears : J. C. Fidler, O.B.E.,
B.SC., PH.D., M.INST.R.

Soft Fruit and Vegetables : W. H. Smith,
B.A., DIP.HORT.

Potatoes : W. G. Burton, B.SC., M.A.

Effects of Orchard Treatment :
B. G. Wilkinson, M.A., PH.D.

COVENT GARDEN LABORATORY

Officer-in-Charge : J. C. Fidler, O.B.E.,
B.SC., PH.D., M.INST.R.

Ditton Laboratory, formerly one of the three laboratories of the D.S.I.R. Food Investigation Board, was built in 1928 to allow work on the gas storage of apples and pears, and on the engineering aspects of the application of refrigeration to the storage of food, to be carried out on a larger scale than was possible at the Low Temperature Research Station, Cambridge.

For experimental work on gas storage the laboratory was equipped with an extensive system of refrigeration and a number of constant temperature rooms together with cabinets, gas holders and other facilities with which the effects of temperature and of the concentration of carbon dioxide and of oxygen on the storage life of fruit could be determined. For work on the application of refrigeration there was a quarter scale model of a ship's hold, large enough to hold 150 tons of fruit and fitted with internal and external coolers so that the efficiency of the various systems which were used to cool cargoes could be compared.

Gas storage of apples, which had been developed at the Low Temperature Research Station on a laboratory scale in the 1920s, was first used on a commercial scale in 1928. It developed rapidly from 1928 to 1940 as the temperatures and concentrations of oxygen and carbon dioxide most suited to the more important varieties of English apples and pears were determined and the ways whereby these conditions could be obtained were discovered. Methods had to be found for making stores gas tight and for controlling the concentrations of carbon dioxide and oxygen by restricting ventilation and by "scrubbing" out excessive concentrations of carbon dioxide. By 1940 a new industry—the gas storage of fruit—had been created and was well established in England.

Experiments carried out in the experimental hold gave information about rates of cooling stacks of fruit, the need for dunnage, the leakage of heat into stores and the performance of coolers. It provided much of the data that have been used in building precooling plants in South Africa, Australia and New Zealand and in designing modern refrigerated ships.

The work on storage was much curtailed by the war and the ship's hold was used for work on the icing of aircraft. When work on storage was taken up again, the relative importance and value of certain horticultural crops had changed and the shortage and cost of labour had rendered certain of the earlier methods unprofitable. In particular, potatoes had acquired more importance and the practice of storing them in clamps had become unsatisfactory. New methods of marketing which were being developed in America were also being introduced into England. The need for research was more widely recognised and the Refrigerated Cargo Research Council, which was set up by the shipping companies to consider problems of refrigeration at sea, took over the responsibility for work of the type formerly carried out in the model ship's hold at Ditton. The Fruit and Vegetable Canning and Quick Freezing Research Association was formed to extend the work on the preservation of fruits and vegetables by canning and quick freezing carried out at the Chipping Campden Research Station. Hence the work of Ditton came to be limited to problems of harvesting, handling, storage and marketing of fresh fruits and vegetables. It now covers such problems as the assessment of quality and characteristics of fruit and vegetables when harvested (their state of maturity, their composition in relation to season and orchard conditions), the changes they undergo after harvest, the most suitable conditions of storage for reducing these changes to a minimum, and the ways by which the conditions can be obtained in storage and in marketing. The work demands the co-operation of chemists, biochemists, plant physiologists, mycologists, bacteriologists, physicists and engineers; and special facilities of refrigeration and constant temperature storage space are required for the work. The refrigeration plant was renewed in 1953; in 1957 the ship's hold was dismantled and has since been replaced by new constant temperature chambers. A large barn, built in 1947 for the work on storage of potatoes, was converted in 1955 into an engineering laboratory and now houses a wind tunnel. The laboratory has a mobile cold store for work in the field and an insulated container for studying problems of transport.

The Covent Garden Laboratory, established in 1926 to provide a base from which observations could be made on fruit passing through the market, has been attached to Ditton Laboratory since 1945.

The scientific and experimental staff on 31st March, 1960, numbered twenty-two.

CURRENT WORK

Storage Trials. Small-scale gas-storage trials have been undertaken with some of the less widely-grown varieties of apple (Merton Wonder, Merton Beauty, Barnack Beauty, Crawley Beauty, Rome Beauty) and pear (Fertility, Beurre Hardy, Packham). The relative effects of temperature and of CO₂ on storage life have been observed in Conference and Comice pears stored in air at 30°F., and in air and 0, 4, 8 and 12 per cent CO₂ at 32°F. and 35°F.

Further data have been obtained on the times of exposure, at different temperatures, to different concentrations of CO₂ to produce brown heart in Newton Wonder apples.

Larger scale trials of the storage of apples in low concentrations of oxygen in the absence of carbon dioxide have indicated the advantage of storage at lower concentrations of oxygen than had previously been thought advisable. The incidence of scald was reduced at concentrations of oxygen below 3 per cent.

Blackcurrants have been stored at 32°, 35°, 40°, 50° and 60°F., in 25 and 50 per cent CO₂. The best conditions for the storage of blackcurrants awaiting processing are probably 35°F. with 50 per cent CO₂ during the first week of storage and 25 per cent CO₂ thereafter. Under these conditions the storage life is 4-6 weeks.

Further data have been obtained on the concentrations of CO₂ which can safely be used in the marketing or storage of strawberries, raspberries and cherries.

Measurements made of the temperature of beetroot stored on a commercial scale in barns or clamps showed that storage below 34°F. often resulted in injury.

Physiological Diseases. Observations on the effect of weather conditions during late July and August on the incidence of superficial scald of apples during storage led to the prediction that the summer of 1959 would be followed by very severe scald on susceptible varieties. This was borne out. The theory that increased water supply to the trees during this period, in a dry summer, would reduce scald was tested experimentally. The fruit from non-irrigated trees developed twice as much scald as that from irrigated trees.

Warming apples in 20 per cent CO₂ at a certain time during the storage period has been found to reduce the incidence of low temperature injury; warming in air reduced scald.

Fungal Diseases. Experiments carried out in co-operation with other research stations have demonstrated that organic mercurial sprays applied during the winter afford some measure of control in the following season of the lenticel rotting of stored apples caused by *Gloeosporium* spp.

In co-operation with East Malling Research Station, a study has been made of the dispersal of spores of *G. album* and the infection of fruit throughout the growing season. The resistance of apples to rotting by *G. perennans* has been studied in relation to the growth of the fruit and to its content of chlorogenic acid and other phenolic compounds.

The effect of orchard management on the composition and keeping quality of apples. This investigation has continued in co-operation with the East Malling Research Station.

In manurial trials of 16 treatments, seasonal effects sometimes outweigh treatment effects, but in the same year the effects of treatment are consistent and predictable, and low temperature breakdown is negatively correlated with the concentrations of potassium, phosphorus and titratable acid in the fruit.

The production of ethylene by fruits. A gas chromatograph fitted with a flame ionisation detector has been developed for estimating ethylene. This

method has made it possible to estimate ethylene in 1 ml. samples at concentrations down to 1 p.p.m. The amounts of ethylene present in apple stores have been measured throughout the storage season, and the stage of ripening at which fruits begin to produce ethylene and the rates of subsequent production have been studied.

Hydrocooling. Laboratory trials have been undertaken on hydrocooling spring cabbage, cauliflowers, lettuce and other vegetables. Observations have been made on the rates of cooling in commercial hydrocoolers, the subsequent rates of rise in temperature during marketing and their effects on deterioration.

Prepackaging. Experiments are being undertaken on the permeability of films and the conditions of carbon dioxide and oxygen within film packages containing fruits and vegetables.

Covent Garden Laboratory. Observations have been made on the short-term storage of flowers. Experimental data are being collected for a revision of a leaflet on "Entrepot storage." Further trials have been carried out on the effect on the incidence of scald of dipping apples in a solution of diphenylamine and other substances.

Potatoes. The use of nonyl alcohol is now well established and no further laboratory work is being undertaken. The volatiles produced by potatoes are being collected and identified, and their relation to dormancy is being explored. The effects of season, culture, storage and variety on sugar content, dry matter and suitability for frying and chipping are being studied. The effects of removal of the haulm, and of the date of lifting and subsequent storage temperature on dormancy and sprouting are being examined.

A survey of the effects of harvesting and handling practices and the extent of damage on the storage quality of potatoes has been conducted in co-operation with the National Institute of Agricultural Engineering and the Potato Marketing Board.

Biochemistry. At the end of several years' work on Cox's Orange Pippin apples little obvious correlation has been found between various manurial treatments and general respiration, protein content and net increase in protein during the development of the respiration climacteric. Seasonal variations appear to be greater than variations within the various manurial treatments. While the concentration of nitrogen compounds falls, in the pulp tissue, during growth on the tree, it remains practically constant in the peel.

The respiration rate and the increased respiration due to added malate (malate effect) are highest in the outer layers of the peel of the fruit. The malate effect is very high in young, stored apples and in these fruits citrate is also effective in raising the CO_2 -output of peel tissue. While it has now been possible to obtain particles from the pulp of English apples having some of the properties of mitochondria, evidence is accumulating that pathways other than the Krebs cycle are important in the acid metabolism of the fruit. These pathways are being investigated with special reference to the period of the respiration climacteric.

Engineering. The Horticultural Improvements Bill has stimulated the building of cold stores. Discussions have been held with N.A.A.S. Horticultural and Machinery Officers and with the Land Service Officers to outline the specifications for the types of cold stores which could qualify for grants. A

whole day's meeting of the Institute of Refrigeration was held at Ditton in March, 1960, to discuss the construction of gas stores and cold stores for fruits and vegetables.

The rates of absorption of CO_2 by unopened bags of lime have been examined to provide data about the optimum amounts of lime to use in lime "scrubbers." The performance of a lime scrubber attached to a commercial store was followed.

Large bins, holding 16-24 bushels, are now being used for the harvesting and storage of fruit, and information is wanted on the need for ventilation holes in the bottoms. Measurements have therefore been made on the rates of cooling and the distribution of temperature in bins of different types of construction.

Further tests have been made on new types of insulating and gas-proofing materials. Further data have been obtained on the effect of icing on the performance of coolers.

LOW TEMPERATURE RESEARCH STATION

Downing Street, Cambridge

Director : E. C. Bate-Smith, PH.D., M.INST.R., F.L.S.

Deputy Director: M. Ingram, M.A., PH.D.

MEAT

Head of Department : Vacant

BIOCHEMISTRY

R. A. Lawrie, B.SC., PH.D., F.R.I.C.

J. G. Sharp, M.A., B.SC., PH.D.

J. R. Bendall, B.A.

A. G. Kitchell, B.SC., PH.D.

PLANT PRODUCTS

Head of Department : Vacant

L. W. Mapson, B.A., PH.D.

F. A. Isherwood, B.SC., M.A., PH.D.

H. G. Wager, M.A., B.SC., PH.D.

T. Swain, B.SC., PH.D., A.R.I.C.

REFRIGERATION

Head of Department : R. Gane, M.A.,
M.SC., PH.D., A.R.I.C.

EGGS AND POULTRY

Head of Department : J. Brooks,*

O.B.E., B.SC., PH.D.

D. H. Shrimpton, M.A., PH.D.

PROTEIN AND ION-EXCHANGE

Head of Department : S. M. Partridge,
M.A., B.SC., PH.D., F.R.I.C.

FATS AND LIPIDS

Head of Department : C. H. Lea,
D.SC., SC.D., PH.D., F.R.I.C.

P. A. T. Swoboda, M.SC., PH.D.

MICROBIOLOGY

Head of Department : M. Ingram,
M.A., PH.D.

BACTERIOLOGY

Miss E. M. Barnes, B.SC., D.PHIL., A.R.I.C.
B. P. Eddy, M.A., B.SC., PH.D.

RADIATION

D. N. Rhodes, B.SC., PH.D.
Mrs. M. J. Pleasance, B.SC., PH.D., A.R.C.S.

Secretary: Miss D. E. Arthington

Executive Assistant: R. Johnson

* Died 2nd October, 1960.

The Station was established by the Department of Scientific and Industrial Research in 1922, to study the scientific principles of food preservation and in particular their application to the preservation of meat and fruit. At the time the main problems were the prevention of wastage in cargoes of fruit from the

distant Dominions and finding better ways of freezing beef. The experimental refrigeration installation at the Low Temperature Research Station was the most complete of its kind in the world. The first Director, Sir W. B. Hardy, recognised that studies of the rate of chemical change at different temperatures were useless unless the temperatures could be maintained constant within a very narrow range, and that constant temperatures differing by only a few degrees over a very wide range would be required. This meant that the equipment would need to consist of numerous not very large rooms. The present installation consists of 40 constant temperature rooms ranging from -20°C (-4°F) to 30°C (84°F), with the greatest number between -5°C (23°F) and $+5^{\circ}\text{C}$ (41°F), i.e. just below and just above the freezing point of fresh foods.

From the early studies emerged the gas-storage of fruit, the quick-freezing of meat and fish, and the gas-transport of chilled beef from Australia and New Zealand. After its enlargement in 1928 eggs and poultry were added to the commodities for which the Station is responsible.

During the war the main effort of the Station was directed to the dehydration of foods. Processes developed in the laboratory for the dehydration of meat, eggs and vegetables were put into operation by the Ministry of Food, to whom staff were seconded as technical advisers for the period of the war. The extension of the staff's experience in these directions brought to light many novel problems fundamentally concerned with the preservation of quality in stored and processed foods, and these formed the starting point for a great deal of the work now engaging the attention of the Station. More recent activities are the detailed examination of newer methods of preservation such as irradiation and the use of antibiotics. The present stage of research in these topics is briefly reported below.

On 1st July, 1959, the Station was transferred to the Agricultural Research Council.

The building occupied by the Station is held on a ten-year lease from the University of Cambridge. On the expiry of the lease in 1966, it will not be possible for the University to renew it, on account of pressure of space for the teaching departments. The question has soon therefore to be faced of the provision of fresh accommodation for the Station.

On 31st March, 1960, the scientific and experimental staff numbered forty-seven.

CURRENT WORK

Meat

Biochemistry. The main purpose of the work in this section is to improve the quality of meat by treatment of the animal before slaughter and of the carcass after slaughter. This means, essentially, a study of all the events included in the process of *rigor mortis* and of factors which in any way affect the activities of micro-organisms responsible for the deterioration and decay of the meat. Especial attention is being paid at the moment to the injection of physiologically active substances which may be expected to improve the tenderness and flavour of the meat.

Carcass quality. The work under this heading is at present being carried out by a small group attached to the University School of Agriculture. It is

hoped shortly to provide a laboratory at an abattoir near Cambridge for an extension of this work, and also to provide improved facilities for biochemistry and microbiology in the slaughterhouse. Studies of carcase quality are much needed in order to evaluate the results of breeding and feeding experiments, and as a guide to the assessment of value of meat animals on the market.

Microbiology. Much attention is being paid to the microbiology of curing brines, to the hygienic problems of packaged sliced bacon, and to the factors affecting the level of nitrate and nitrite in cured meats. A discovery of considerable practical importance is that a great deal of the nitrate added to the pickle does not appear as nitrite in the cured meat, but is destroyed in an unknown manner.

Poultry

Quality. Newer methods of marketing are giving rise to problems of preservation and culinary quality. Perhaps the most conspicuous of these is the complaint of tastelessness in broiler chickens, but this is more concerned with production and presentation than with preservation. Questions such as rapid cooling, evisceration, chilling or freezing, in the special circumstances prevailing in this country, and the use of antibiotics are being investigated.

Laboratory work is in progress on the physiology of the domestic fowl with particular reference to the physiology of the digestive tract.

Microbiology. The continuing introduction of new plastic wrapping films has emphasised the lack of information concerning the effects of the physical properties of these films, particularly their permeability to gases, on the tissue respiration of the wrapped carcasses, and of the combined influence of these physical and physiological effects on the microbiology of the spoilage flora. Preliminary experiments, in which wrapped eviscerated carcasses were held chilled, have indicated the complexity of these interrelationships, but one result of practical significance has been obtained; namely, that when an impermeable wrap which was evacuated was used, the rate of bacterial multiplication was slowed and the shelf-life was extended.

Eggs

Under modern conditions the most serious single cause of loss in the marketing of eggs is breakage. A study of the variation of strength of shell with composition has brought to light the importance of traces of some elements and their distribution in the mineral matrix. Feeding tests are in progress to determine what prospects there are of improving strength of shell by control of diet.

Resistance to infection of the egg by bacteria decreases with the age of the egg. This has been shown to be due to the extent to which bacteria multiply on the egg membrane rather than within the egg itself. There is a spontaneous change with time in the membrane which makes it more susceptible to bacterial attack, and this change becomes more rapid at about the twelfth day after laying.

Pasteurisation of liquid whole egg has been introduced as a method of combating contamination with *Salmonellae*. The selection of suitable conditions of pasteurisation so that the baking qualities of the egg are not impaired is

critical. A biochemical test based upon the decrease of activity of α -amylase is giving promising results.

Fruits and Vegetables

Potatoes. The after-cooking blackening of potatoes was shown to be due to a complex of iron with chlorogenic acid, which was formed to a decreasing extent the more citric acid was present in the tissue. This negative correlation between blackening and citric acid content has been shown to hold in widely different growing conditions, both with regard to soil and weather. In collaboration with the National Institute of Agricultural Botany, attempts are being made to increase citric acid content in the tuber by manurial treatments both in pot experiments and in the field.

Progress has also been made in the control of enzymic browning of pre-packaged raw potato chips. Work has been begun on the problem of enzymic browning with the aid of U.S.D.A. counterpart funds.

Peas. The problems with this commodity are the shortness of the season for the processing factories and the rapid loss of quality of the fresh produce. Both of these are problems which can be alleviated by storage at reduced temperatures, but control of the respiratory metabolism by the use of carbon dioxide and the exclusion of oxygen is also a possible method of control. Work is therefore in progress on the physiological processes in green peas. Recent results indicate that the Krebs cycle is of minor importance in these processes, and that there may be opportunities for useful application of gaseous inhibitors of metabolism in commercial practice.

Imported fruits and cacao. The control of ripening in "green" fruits such as South African plums and West Indian bananas presents many problems. The transport problems are being studied in collaboration with the Refrigerated Cargo Research Council, and laboratory work is in progress on the biochemistry of the ripening process itself. In this process, in the two cases mentioned, the reduction of astringency by polymerisation of leuco-anthocyanic tannins is one of the more important features, linking the work on these commodities with that on cacao quality, which has been in progress for a number of years.

General Biochemistry, Biophysics, and Microbiology of Foods.

The possibility of solving practical problems in food preservation often depends on a knowledge of the properties of particular classes of constituents, and the development of methods of following changes in them. This is particularly true of the more complex constituents such as structural proteins, lipoproteins, phospholipids, cell-wall polysaccharides, lignin, and the vegetable tannins.

In the case of proteins, the particular subjects of study are the components of connective tissue, collagen, elastin and mucoid (the last being a protein-polysaccharide complex.) The phospholipids of egg-yolk have been selected as the main material for the study of the physical and chemical stability of phospholipids, especially their stability towards atmospheric oxidation. The work on lignin and tannins has opened up a little-explored field of plant biochemistry, that of the plant phenolics, and as has been mentioned above, this has already provided an answer to a number of practical problems in connection with the storage of fruits and vegetables.

Further information about the Station's work may be found in its published annual report.

PEST INFESTATION LABORATORY

London Road, Slough, Bucks.

Director: G. V. B. Herford, C.B.E., M.SC.

Deputy Director: E. A. Parkin, PH.D., D.SC., D.I.C., M.I.BIOL.

BIOLOGY

Head of Department: M. E. Solomon,
M.SC., M.I.BIOL.

G. E. Woodroffe
C. W. Coombs, M.SC.
D. H. Burges, B.SC., PH.D.
L. P. Lefkovitch, B.SC.

INSECTICIDES

Head of Department: E. A. Parkin,
PH.D., D.SC., D.I.C., M.I.BIOL.

P. S. Hewlett, B.SC., PH.D., M.I.BIOL.
A. A. Green, M.B.E., M.I.BIOL.
J. A. Hope, B.SC.
C. E. Dyte, B.SC., M.I.BIOL.

FUMIGANTS

Head of Department: W. Burns Brown,
M.SC., F.R.I.C., A.R.C.S., D.I.C.

R. W. Howe, D.SC., A.R.C.S., M.I.BIOL.
S. G. B. Heuser
G. Surtees, M.SC., M.I.BIOL.

BIOCHEMISTRY

Head of Department:
F. P. W. Winteringham, F.R.I.C., M.I.BIOL.

S. E. Lewis
R. G. Bridges, B.SC.
J. P. Heslop, M.SC.

STORAGE

Head of Department: Miss M. B. Hyde,
M.SC., M.I.BIOL.

MYCOLOGY

Head of Department: G. Ayerst, B.SC.

TROPICAL LIAISON

Head of Department: D. W. Hall,
B.SC., PH.D.

F. N. Wright, M.A.

Secretary: H. W. Cooke

On the 31st March, 1960, the scientific and experimental staff of the Laboratory numbered fifty-three.

The Laboratory was set up in 1940 by the Department of Scientific and Industrial Research, at the request of the food-handling industry, to undertake research on the insect pests of stored products and their control.

Although the demand for this work was based on pre-war conditions, the newly-formed Laboratory was confronted with the new and urgent problem of safeguarding security stocks of grain and other foodstuffs. Being intended for long-term storage, these large stocks provided ideal conditions for the development of heavy infestations of insects and mites. Work was therefore undertaken on the biology and ecology of the pests, and their effect on the foodstuffs, and on the physics of bulk grain in relation to thermal conductivity, moisture relations, and penetrability by gases. Work on chemical control involved the study of the toxicity of fumigant gases and contact insecticides to the different species of insects and mites in their different developmental stages, the examination of chemical residues which might result from the fumigation or other treatment of foodstuffs, and the development of methods of application of such fumigants and insecticides as were shown to be safe for use on a commercial scale.

The inspection of foodstuffs and the application of control measures were undertaken by the Infestation Control Division of the Ministry of Food, and broadly speaking the same division of responsibility holds good today.

As a result of this combined work there has been a marked reduction in the general level of infestation in warehouses and food factories throughout Britain, but infested cargoes still arrive at British ports. For some years, therefore, the Laboratory has also been increasingly concerned in improving the quality of our infestable imported foodstuffs. A Tropical Liaison group, paid for by the Colonial Office, is responsible for investigating conditions of food storage in appropriate territories overseas, and for recommending measures for reducing infestation.

From this brief summary it will be apparent that the Laboratory is primarily concerned with the insect pests of stored products, and of foodstuffs in particular. Certain "domestic" insects have also required attention, and work has been done, for example, on fly infestations of slaughterhouses and refuse tips, and on ants and cockroaches in hospitals and factories. The Laboratory also undertakes research on mycological problems arising from the storage of various commodities. More basic research is undertaken in the Biochemistry Department on the mode of action of insecticides and particular attention is being paid, at the request of the World Health Organisation, to the problem of insect resistance to insecticides.

CURRENT WORK

The Laboratory produces annual reports, and the following summary of a few items of current work is drawn from "Pest Infestation Research 1959."

Infestation of Malt. Malt is susceptible to attack by insects, especially by the Khapra beetle, *Trogoderma granarium*, which is able to attack very dry foods. This beetle is also unusually resistant to most insecticides. Research has shown that its development is greatly retarded at temperatures below 23°C, and the possibility has, therefore, been explored of cooling malt after kilning. A practical demonstration of the value of doing this was afforded by two binsful of malt, each of 270 tons, one of which had been experimentally cooled before storage.

After nine months' storage in infested premises the cooled malt showed little or no sign of developing insect population, in striking contrast to the uncooled malt, which was heavily infested.

Fossae in Malta. At the invitation of the Maltese Government, Miss Hyde visited the island in 1958 to supervise an experiment in one of the ancient fossae, or grain storage pits, which had been treated to render it impervious to leakage of water vapour and atmospheric gases. Miss Hyde paid a second visit this year, at the end of the experimental period, to observe the effect of the treatment, which had been highly successful.

Moisture Meter for use on Copra. A robust, portable meter, suitable for use "in the field" has been developed and is now being tested under commercial conditions overseas.

The meter is based on a standard 250 volt Megger ohmmeter, used with a double spike electrode, and has the advantages of being robust, very rapid in operation not requiring batteries.

Protection of bagged Groundnuts by Malathion. An interesting example of the "scale effect," which has to be borne in mind when translating small-scale research into practical application, has been provided by the results obtained

when large sacks of groundnuts were sprayed experimentally with malathion to protect them against insect attack. The same treatment, which had been highly successful when applied to miniature sacks, gave very little protection on the larger scale.

Further work has shown that insects confined at various positions inside a small sack were killed without coming into contact with the treated sacking, and that this effect decreased with increasing distance from the surface. Small sacks have a much higher proportion of treated surface area to a given weight of nuts, and the insects had less opportunity to move well away from the treated area.

Insecticidal Lacquers. Lacquers containing certain synthetic insecticides such as dieldrin and endrin have marked advantages over other methods of formulation. Chief among these are a long effective toxicity to insects and the ability to regenerate a surface layer of insecticide when this has been removed, e.g. by washing.

A lacquer containing malathion, prepared and tested in the Laboratory, appears promising in as much as it retains its toxicity to insects over a long period. Malathion is much less toxic to man and animals than are dieldrin and endrin, which, though effective in lacquer formulations, are too dangerous for use in contact with or near to foodstuffs.

Significance of Low levels of Infestation. Little is known of the significance of very low levels of insect populations in foodstuffs such as may be represented by the survivors of partially successful fumigation. Experiments to investigate this very practical problem are now under way.

Fumigation of Tobacco with Methyl Bromide. After a long series of tests, a technique has been worked out which, experimentally, gives a fairly even distribution of the gas throughout a case of tobacco. No significant effect on the smoking quality of the treated tobacco could be detected. Facilities are being sought for large-scale trials, so that the success of the technique may be assessed on the scale at which treatment would ultimately be given.

Gas Chromatography, using a column of grain. The differential penetration of carbon tetrachloride, ethylene dichloride and ethylene dibromide into grain, noted in large-scale fumigations, has led to the successful use of a column of barley as a means of assaying the components of mixtures of chlorinated hydrocarbons, which are frequently used in practice.

Insect Resistance to Insecticides. Intensive research is being undertaken, on behalf of World Health Organisation, on the problem of insect resistance to dieldrin. Up to date the work has shown that resistance of the adult housefly (*Musca domestica*) and of the larvae of a malaria-carrying mosquito (*Anopheles gambiae*) is not due to lack of absorption of the insecticide through the insect cuticle, or to a greater overall metabolism of the insecticide or to a greater rate of excretion of the insecticide. A fresh attack on the problem has been made, involving the synthesis of new insecticides related to dieldrin and a study of the site of action of dieldrin in the susceptible insect.

STATISTICS

A.R.C. UNIT OF STATISTICS

University of Aberdeen, Meston Walk, Old Aberdeen

Director : D. J. Finney, M.A., SC.D., F.R.S., F.R.S.E.

Senior Scientific Officer: M. R. Sampford, M.A., D.PHIL.

The Unit was established in 1954 to provide a statistical service for agricultural research in Scotland. It assists the research institutes and agricultural colleges by advising individual members of staff on the special statistical problems of their work, both in the planning and design of experiments and in the analysis and interpretation of results. Particular attention is given to research programmes that involve several institutes or colleges collaboratively. Members of the Unit are also engaged in statistical research, with especial emphasis on problems which arise in the course of the statistical services provided, or which are in other ways related to agriculture. The Unit is attached to the University Department of Statistics, and has been placed under the direction of the Reader in Statistics.

On 31st March, 1960, the Unit consisted of five graduates and a small group of computing clerks.

Much of the work undertaken by the Unit is too diverse to be described briefly, since it consists of advice on particular research projects for a large number of different people. Three important categories are advice on the design and analysis of field experiments on soft fruit for the Scottish Horticultural Research Institute, similar advice in relation to milk constitution and pasture trials for the Hannah Dairy Research Institute, and assistance to the Hill Farming Research Organisation on questions ranging from small-scale botanical experiments to long-term observational records on the performance of ewes. A great amount of assistance continues to be given to the North of Scotland and the West of Scotland Agricultural Colleges.

In recent years, the Unit has been closely concerned with the Survey of Fertiliser Practice in Scotland. The field work in this Survey is undertaken by the three agricultural colleges and the planning is now reduced to a routine, but the analysis and the preparation of reports within the Unit still take much time even though most of the basic computing is now done on the electronic computer at Rothamsted. Each year six districts are surveyed, and an attempt is made steadily to improve the scope of the questions asked, so that the facts of fertiliser use may be related to the whole pattern of farm management in a district.

Research within the Unit includes continued study on the theory of selection, development of designs for extensively replicated very small field experiments, statistical techniques for estimating digestibility, and the study of efficiency of design and estimation in the Fertiliser Survey.

In September, 1959, the second two-week course on elementary statistics in agricultural research was held at the Hannah Dairy Research Institute, for the benefit of about 25 members of the staff of that Institute and of the West of Scotland Agricultural College.

A.R.C. STATISTICS GROUP

School of Agricultural, University of Cambridge

Officer-in-charge : R. C. Campbell, M.A., PH.D.

(Lecturer in Agriculture (Statistics), University of Cambridge)

Senior Scientific Officer: J. G. Rowell, M.A.

The Group is professionally responsible to Dr. Yates, Head of the Statistics Department at Rothamsted Experimental Station. Close contact is maintained both with the School of Agriculture and the Statistical Laboratory of the Faculty of Mathematics at Cambridge. The Group's local computing facilities are augmented by the use of the automatic calculator at Rothamsted.

On 31st March, 1960, the scientific and experimental staff of the Group numbered four.

The Group gives advice and assistance in the design and analysis of animal experiments. Most use of this service has been made locally by the Unit of Reproductive Physiology and Biochemistry, the Institute of Animal Physiology and the Houghton Poultry Research Station; one member of the Group specialises in work associated with these laboratories. The other main subject dealt with is carcass quality of cattle and pigs; another member of the Group, who is on the Editing Committee of the National Pig Progeny Testing Board, deals with this work. In addition, the Group designs and analyses the Council's Co-ordinated Experiments on pigs and is associated with certain experiments at the Council's Field Station at Compton.

RADIOBIOLOGY

RADIOBIOLOGICAL LABORATORY

Letcombe Regis, Wantage, Berkshire

Director : R. Scott Russell, M.A., M.Sc., Ph.D.

RADIOCHEMISTRY

E. R. Mercer, B.Sc.

J. D. Burton, B.Sc., Ph.D., A.R.I.C.

PLANT PHYSIOLOGY AND SOIL SCIENCE

L. J. Middleton, B.Sc., Ph.D.

Miss H. M. Squire, M.A., D.Phil.

P. Newbould, B.Sc., B.Agr., D.Phil.

D. A. Barber, B.Sc., Ph.D.

FIELD SURVEYS

F. B. Ellis, B.Sc.(Agric.), Ph.D.

FIELD EXPERIMENTS

G. M. Milbourn, B.Sc.(Agric.), M.Sc.

Secretary: E. A. Tyrer, D.Sc.

The main function of the Laboratory is to investigate the passage of radioactive substances into food chains. The current levels of radioactive contamination in human diet and in other agricultural produce are investigated throughout the United Kingdom and experimental studies are conducted, both in the field and in the laboratory, to elucidate the behaviour of fission products and related substances in soils and plants. The Laboratory also advises the Ministry of Agriculture, Fisheries and Food, the Medical Research Council and the Atomic Energy Authority on these subjects. Close contact is maintained with the Council's Field Station at Compton where work on the veterinary aspects of these problems is in progress.

The headquarters of the Laboratory are at Letcombe Regis, near Wantage, but the majority of the staff are at present accommodated, temporarily, in buildings provided by the Atomic Energy Authority at Grove, Wantage, and at the Council's Field Station at Compton. The building of new laboratories is in progress at Letcombe and it is now expected that the entire staff will be transferred to them early in 1962. On 31st March, 1960, the scientific and experimental staff numbered eighteen.

CURRENT WORK

Experimental Studies. Experimental studies of the behaviour of strontium 90 and calcium in soil have been continued. Attention is being given to the extent to which slow physico-chemical changes may progressively reduce the availability to plants of strontium 90; the results so far obtained indicate that, over a period of two to three years, the availability of strontium 90 is reduced by only a few per cent in this way. The mechanisms whereby strontium 90 moves down undisturbed soil profiles are under investigation; the aim of the work is to ascertain the relative extent of diffusion in the ion exchange system, as opposed to mass movement in water. It is important to distinguish between these two processes, as theoretical considerations indicate that their relative magnitude should change progressively with time.

Field experiments have been continued in various parts of the country to provide quantitative information on the extent to which radioactive strontium enters crops from soil and small-scale studies on the absorption of caesium 137 are in progress.

Investigations on the aerial contamination of plants with strontium 89, caesium 137 and to a lesser extent with other fission products, are being continued. It has previously been shown that the direct entry of strontium 90 into above-ground parts of plants, as opposed to absorption from soil, is the major route whereby human diet is now contaminated. The results of further field and laboratory experiments which strengthen this conclusion were reviewed in the second report of the Laboratory (Agricultural Research Council Radiobiological Laboratory Report No. 2). It appeared that on average about 80 per cent of strontium 90 in milk during 1958 was due to the direct entrapment in the above-ground parts of plants; the remainder being due to absorption from soil.

Methods have been developed to study the movement of naturally-occurring radioactive elements of the uranium and thorium series in soils and in plants. Knowledge of their behaviour is important for assessing the quantity of naturally-occurring radioactivity which enters human diet, and thus contributes to the natural background, with which the extra exposure due to artificial radioactive substances must be compared. In addition, the behaviour of these substances is of interest in the study of ion transport.

In conjunction with the Radiotherapy Unit of the Medical Research Council at Hammersmith Hospital, London, a limited experimental programme has been undertaken to utilise, in plant physiological studies, the special experimental facilities which have been developed in that Unit for other purposes. By using the short-lived radioactive isotope of oxygen (0-15 half-life: 2 minutes) evidence has been obtained that oxygen passes by free diffusion in the gaseous phase from the aerial parts of the plants to their roots, the extent of this movement being apparently related to the magnitude of cortical intercellular spaces. The effects of radiation on young cereal plants have also been studied, in collaboration with the Medical Research Council Unit, to obtain fuller information on the manner in which the supply of oxygen influences radiation sensitivity and to compare the relative biological efficiencies of neutrons and x-rays. It has been shown that young cereal plants which have hitherto been little used in such work are particularly convenient experimental material.

Survey of the entry of strontium 90 from world-wide fall-out into human diet. Results of investigations carried out throughout the United Kingdom during 1959 have been published in the second and third reports of the Laboratory (Agricultural Research Council Radiobiological Laboratory Report No. 2 and No. 3). Since milk contributes over 50 per cent of strontium 90 in the total diet it is examined in particular detail. In addition flour, green vegetables, potatoes, eggs, cheese and tea have been examined. An assessment of the mean level of strontium 90 in the average diet of the population in 1959 has been made and local investigations have been undertaken in parts of the country where high rainfall or special agricultural conditions lead to levels appreciably above the average.

The high rate of fall-out which occurred at the end of 1958 and early in 1959

caused the contamination of milk to rise steeply in the early months of the latter year, so that by June the mean level in milk for the previous 12 months was over 40 per cent greater than in the corresponding value at the end of 1959.

Thereafter, however, there was no further increase, and by the end of the year the monthly values were below those observed 12 months previously. The average level of strontium 90 in the mixed diet of the population as a whole was estimated at 9.0 μc strontium 90 per gram of calcium for 1959; this compared with a value of 5.9 for the previous year. In limited areas where the rainfall is high and the condition of the pastures particularly favours the retention of strontium 90 on edible tissues, the strontium 90 content of milk ranged up to nearly ten times the country-wide average. This situation is believed to be due largely to the strontium 90 being entrapped in a dense mat of stems and surface roots which develops above the ground surface under these conditions. Despite these variations the contamination diet everywhere was below one-tenth of the maximum permissible levels recommended by the Medical Research Council.

Surveys of caesium 137 from world-wide fall-out in human diet. Preparations have been made for surveys on this subject to be commenced in 1961; meanwhile a limited number of samples have been provided for analysis by the Health Physics Division of the Atomic Energy Research Establishment at Harwell.

Joint Investigations with the Atomic Energy Authority of strontium 89 and strontium 90 in the Windscale area. This study was commenced shortly after the accident in Windscale Pile No. 1 in 1957, with the object of determining the extent to which strontium 90 released from the works had contaminated the surrounding agricultural land. The investigation was concluded in 1959 and the results have been published as a joint report of the two organisations. It has been shown that strontium 90 released from the factory was deposited in amounts considerable in relation to world-wide fall-out only within a distance of approximately two miles from the works, but the maximum permissible level in diet, recommended by the Medical Research Council, was not approached. The Atomic Energy Authority has made available, for long-term experimental studies, the most highly contaminated field which adjoins Pile No. 1.

More than two miles from Windscale strontium 90 released from the factory had not been deposited in sufficient quantity for its magnitude relative to world-wide fall-out, to be estimated with accuracy. In the summer after the accident it could, however, be shown that strontium 90 released from the Works made no appreciable contribution to the contamination of milk.

STATE-AIDED AGRICULTURAL RESEARCH INSTITUTES

at date of report

England and Wales

Rothamsted Experimental Station	...	Harpenden, Herts.
East Malling Research Station...	...	Maidstone, Kent.
Grassland Research Institute		Hurley, Maidenhead, Berks.
Agricultural and Horticultural Research Station.		Long Ashton, Bristol.
National Vegetable Research Station	...	Wellesbourne, Warwick.
Welsh Plant Breeding Station		Plas Gogerddan, Aberystwyth.
John Innes Institute		Bayfordbury, Hertford.
Glasshouse Crops Research Institute	...	Rustington, Littlehampton.
Plant Breeding Institute		Trumpington, Cambridge.
National Institute for Research in Dairying.		Shinfield, Reading, Berks.
Foot-and-Mouth Disease Research Institute.		Research Institute (Animal Virus Diseases), Pirbright, Woking, Surrey.
Houghton Poultry Research Station	...	Houghton, Huntingdon.
National Institute of Agricultural Engineering.		Wrest Park, Silsoe, Beds.

Wye College Hop Research Centre ... Ashford, Kent.

Scotland

Macaulay Institute for Soil Research	...	Craigiebuckler, Aberdeen.
Scottish Horticultural Research Institute		Mylnefield, Invergowrie, by Dundee.
Scottish Plant Breeding Station	...	Pentlandfield, Roslin, Midlothian.
Rowett Research Institute		Bucksburn, Aberdeen.
Hannah Dairy Research Institute	...	Kirkhill, Ayr.
Animal Diseases Research Association		Moredun Institute, Gilmerton, Edinburgh.
National Institute of Agricultural Engineering Scottish Station.		Howden, Mid-Calder, Midlothian.
Hill Farming Research Organisation...		48 Palmerston Place, Edinburgh 12.

AGRICULTURAL RESEARCH COUNCIL INSTITUTES AND UNITS

at date of report

Field Station	...	...	...	...	Compton, Newbury, Berks.
Animal Breeding Research Organisation					H.Q.: 6, South Oswald Road, Edinburgh, 9.
Institute of Animal Physiology	...	...	...	...	Babraham, Cambridge.
Poultry Research Centre	...	...	...	...	King's Buildings, West Mains Road, Edinburgh, 9.
Ditton Laboratory	...	...	...	...	Larkfield, Maidstone, Kent.
Low Temperature Research Station				...	Downing Street, Cambridge.
Pest Infestation Laboratory	...	...	...	...	London Road, Slough Bucks.
Unit of Animal Genetics	...	...	...	...	Department of Animal Genetics, Edinburgh University, King's Build- ings, West Mains Road, Edinburgh, 9.
Unit of Biometrical Genetics	...	...	...	...	Department of Genetics, Birmingham University.
Unit of Embryology	...	...	...	...	Department of Zoology, University Col- lege of North Wales, Bangor.
Unit of Experimental Agronomy	...	...	...	...	Department of Agriculture, Oxford University.
Farm Buildings Unit	...	...	...	...	Wrest Park Lodge, Silsoe, Beds.
Unit of Insect Physiology	...	...	...	...	Department of Zoology, Cambridge University.
Unit of Microbiology	...	...	...	...	Department of Microbiology, Sheffield University.
Unit of Plant Morphogenesis and Nutrition.				and	Wye College, Ashford, Kent.
Unit of Plant Physiology	...	...	...	...	Imperial College of Science and Tech- nology, London, S.W.7.
Radiobiological Laboratory	...	...	...	...	Letcombe Regis, Wantage, Berks.
Unit of Reproductive Physiology and Biochemistry.				and	Molteno Institute of Biology and Para- sitology, Cambridge.
Unit of Soil Physics	...	...	...	...	School of Agriculture, Cambridge University.
Unit of Statistics	...	...	...	...	University of Aberdeen, Meston Walk, Old Aberdeen.
Statistics Group	...	...	...	...	School of Agriculture, Cambridge University.
Systemic Fungicide Unit	...	...	...	...	Wye College, Ashford, Kent.
Virus Research Unit	...	...	...	...	Huntingdon Road, Cambridge.
Weed Research Organisation	...	...	...	...	Begbroke Hill, Kidlington, Oxford.

SCIENTIFIC STAFF ATTACHED TO UNIVERSITIES OR RESEARCH INSTITUTES

PLANT BIOCHEMISTRY

School of Biochemistry, Cambridge

R. Hill, M.A., SC.D., F.R.S.

Long Ashton Research Station

D. J. D. Nicholas, D.SC., PH.D., A.K.C., F.R.I.C.

REPRODUCTION

Molteno Institute of Biology and Parasitology, Cambridge

Mrs. C. L. Mann, M.D., PH.D.

VITAMIN ASSAYS

Dunn Nutritional Laboratory, Cambridge

V. H. Booth, B.A., PH.D.

MEAT RESEARCH

School of Agriculture, University of Cambridge

R. W. Pomeroy, M.A., PH.D.

GRASS CONSERVATION

Department of Chemistry, University of Edinburgh

H. T. Macpherson, B.SC., PH.D.

COMMITTEES

(As at 31st March, 1960)

STANDING COMMITTEE ON RESEARCH AFFECTING ANIMALS

Professor P. B. Medawar, C.B.E., M.A., D.SC., F.L.S., F.R.S. (Chairman)
J. D. Alston, J.P.
H. R. Barnell, M.A., B.SC., PH.D., M.I.BIOL.
Professor F. W. Rogers Brambell, B.A., D.SC., PH.D., F.R.S.
R. E. Glover, M.A., D.SC., F.R.C.V.S.
G. N. Gould, J.P., F.R.C.V.S.
F. H. K. Green, C.B.E., M.D., F.R.C.P.
Professor C. S. G. Grunsell, PH.D., M.R.C.V.S.
Professor J. W. Howie, M.D., M.R.C.P., F.R.F.P.S.
Elwyn Jones, O.B.E., J.P.
Professor Sir Hans A. Krebs, M.A., M.D., D.SC., F.R.C.P., F.R.S.
Professor P. L. Krohn, B.A., B.M., B.CH.
T. R. R. Mann, M.D., PH.D., SC.D., F.R.S.
Professor K. Mather, C.B.E., D.SC. PH.D., F.R.S.
Professor C. L. Oakley, M.D., B.S., D.SC., F.R.S.
Sir John N. Ritchie, C.B., B.SC., F.R.C.V.S., D.V.S.M., F.R.S.E.
Professor C. H. Waddington, C.B.E., M.A., SC.D., D.ES SC., F.R.S.
Professor W. L. Weipers, B.SC., F.R.C.V.S., D.V.S.M., F.R.S.E.
Professor E. G. White, D.SC., F.R.C.V.S.
Professor V. B. Wigglesworth, C.B.E., M.A., M.D., B.CHIR., F.R.S.

STANDING COMMITTEE ON RESEARCH AFFECTING PLANTS AND SOILS

Professor S. J. Watson, C.B.E., D.SC., F.R.I.C., F.R.S.E. (Chairman).
Professor T. A. Bennet-Clark, M.A., PH.D., F.R.S.
E. G. COX, T.D., D.SC., F.INST.P., F.R.I.C., F.R.S.
David Lowe, C.B.E., F.R.S.E.
Professor K. Mather, C.B.E., D.SC., PH.D., F.R.S.
W. C. Moore, C.B.E., M.A.
Professor G. Pontecorvo, DR.AGRIC., PH.D., F.R.S.
F. Rayns, C.B.E., M.A.
H. G. Sanders, M.A., PH.D.
*R. K. Schofield, M.A., PH.D., F.INST.P.
Professor P. T. Thomas, B.SC., PH.D.
Professor R. L. Wain, D.SC., PH.D., F.R.I.C., F.R.S.
Professor C. W. Wardlaw, D.SC., PH.D., F.R.S.E.
Professor V. B. Wigglesworth, C.B.E., M.A., M.D., B.CHIR., F.R.S.
Professor W. T. Williams, B.SC., PH.D.
F. Yates, SC.D., F.R.S.

*Died 8th June, 1960

SOIL SURVEY RESEARCH BOARD

Sir William G. Ogg, M.A., B.SC., PH.D., LL.D., F.R.S.E. (Chairman).
J. Macdonald, C.B.E., B.SC., F.R.S.E.
W. Morley Davies, M.A., B.SC., F.R.I.C.
G. H. Mitchell, D.SC., F.R.S.
J. B. E. Patterson, M.SC., F.R.I.C.
N. H. Pizer, M.SC., PH.D., F.R.I.C.
Professor Sir William J. Pugh, O.B.E., D.SC., F.R.S.
D. Rhind, O.B.E., B.SC., F.L.S.
*R. K. Schofield, M.A., PH.D., F.INST.P.
A. M. Smith, D.SC., PH.D.
Professor L. Dudley Stamp, C.B.E., B.A., D.SC., D.LITT. LL.D.
A. B. Stewart, M.A., B.SC., PH.D., F.R.I.C., F.R.S.E.
Professor T. Wallace, C.B.E., M.C., D.SC., F.R.I.C., V.M.H., F.R.S.
A. S. Watt, B.A., PH.D., F.R.S.
A. Woodburn.
A. Muir, B.SC., PH.D. (Technical Secretary).

* Died 8th June, 1960

VETERINARY THERAPEUTIC TESTING BOARD

*†M. A. C. Noble, M.P. (Chairman).
*N. T. J. Bailey, M.A., D.SC.
N. M. Black, M.R.C.V.S.
*Professor G. Brownlee, D.SC., PH.D., F.P.S.
*J. W. Bruford, M.R.C.V.S.
*K. R. Capper, B.PHARM., PH.D., F.P.S., D.I.C.
W. S. Gordon, C.B.E., PH.D., M.R.C.V.S., F.R.S.E.
*F. H. K. Green, C.B.E., M.D., F.R.C.P.
*R. Paisley.
*R. Scarisbrick, M.A., PH.D., M.R.C.V.S., A.R.I.C.
J. B. White, M.R.C.V.S.
E. Wilkinson, M.R.C.V.S.
*W. R. Wooldridge, M.SC., PH.D., F.R.C.V.S., F.R.I.C.

* Also a member of the Board's Consultative Committee.

† Resigned May, 1960.

FARM BUILDINGS RESEARCH COMMITTEE

Sir Walter Drummond, D.SC., M.INST.C.E., M.I.MECH.E. (Chairman).
W. H. Cashmore, C.B.E., B.A., N.D.A.
S. W. Cheveley, O.B.E.
J. Crooks.
Professor R. Llewelyn Davies, M.A., A.R.I.B.A.
D. Grant, F.R.I.C.S.
W. O. Kinghorn, B.SC.
R. G. A. Lofthouse, F.L.A.S., F.R.I.C.S.
P. J. Macfarlan, B.SC., N.D.A., N.D.D.
R. S. Morton, A.R.I.B.A., A.M.T.P.I.
G. D. Nash, A.R.I.B.A.
H. J. Rathbone, F.L.A.S.
C. Robinson, F.R.I.C.S., A.A.I.
F. G. Sturrock, M.A., B.SC., N.D.A., N.D.D.
J. K. W. Slater, M.A., M.SC. (Member and Technical Secretary.)

FOOD RESEARCH COMMITTEE

D. Lowe, C.B.E., F.R.S.E. (Chairman).
H. R. Barnell, M.A., M.Sc., Ph.D., M.L.Biol.
Professor T. A. Bennet-Clark, M.A., Ph.D., F.R.S.
E. G. Cox, T.D., D.Sc., F.Inst.P., F.R.I.C., F.R.S.
T. R. R. Mann, M.D., Sc.D., Ph.D., F.R.S.
Professor P. B. Medawar, C.B.E., M.A., D.Sc., F.L.S., F.R.S.

FARMING ACTIVITIES

J. D. Alston, J.P. (Chairman).
R. E. Glover, M.A., D.Sc., F.R.C.V.S.
Elwyn Jones, O.B.E., J.P.
David Lowe, C.B.E., F.R.S.E.
F. Rayns, C.B.E., M.A.
H. G. Sanders, M.A., Ph.D.
Sir William K. Slater, K.B.E., D.Sc., F.R.I.C., F.R.S.
F. Yates, Sc.D., F.R.S.

TECHNICAL COMMITTEES

ANIMALS

FOOT-AND-MOUTH DISEASE

(Governing Body of Foot-and-Mouth Disease Research Institute, Pirbright, Surrey)
S. W. Cheveley, O.B.E. (Chairman).
Sir Christopher Andrewes, M.D., F.R.C.P., F.R.S.
Professor A. W. Downie, M.D., D.Sc., F.R.S.
H. J. Johns, C.B.
Professor H. G. Lamont, O.B.E., D.Sc., M.R.C.V.S.
Professor H. B. Maitland, M.D., M.Sc.
Sir John Ritchie, C.B., B.Sc., F.R.C.V.S., D.V.S.M., F.R.S.E.
Professor Alex Robertson, M.A., B.Sc., Ph.D., M.R.C.V.S., F.R.I.C., F.R.S.E.

NUTRIENT REQUIREMENTS OF FARM LIVESTOCK

D. P. Cuthbertson, C.B.E., M.D., D.Sc., LL.D., F.R.S.E. (Chairman).
Professor R. G. Baskett, O.B.E., M.Sc., F.R.I.C.
A. W. Boyne, B.Sc.
R. Braude, D.Sc., Ph.D.
A. Eden, M.A., Ph.D., F.R.I.C., Dip.Agric.
S. K. Kon, D.Sc., Ph.D., F.R.I.C.
F. H. Moul, M.Sc.
Professor Alex Robertson, M.A., B.Sc., Ph.D., M.R.C.V.S., F.R.I.C., F.R.S.E.
J. A. B. Smith, C.B.E., D.Sc., Ph.D., F.R.S.E.
D. B. Wallace, M.A.
I. A. McK. Lucas, M.Sc. (Technical Secretary).

PIG RESEARCH

Professor L. P. Pugh, M.A., B.SC., F.R.C.V.S. (Chairman).
Professor R. G. Baskett, O.B.E., M.SC., F.R.I.C.
H. R. Davidson, M.A., DIP.AGRIC.
H. P. Donald, D.SC., PH.D., F.R.S.E.
*J. Duckworth, B.S.A., D.SC., F.R.S.E.
A. Eden, M.A., PH.D., F.R.I.C., DIP.AGRIC.
H. I. Field, M.SC., M.R.C.V.S.
E. G. Johnson.
Professor H. G. Lamont, O.B.E., D.SC., M.R.C.V.S.
P. J. Macfarlan, B.SC., N.D.A., N.D.D.
Sir John Ritchie, C.B., B.SC., F.R.C.V.S., D.V.S.M., F.R.S.E.
Professor Alex Robertson, M.A., B.SC., PH.D., M.R.C.V.S., F.R.I.C., F.R.S.E.
R. Braude, D.SC., PH.D. (Member and Technical Secretary).

* Died 11th April, 1960.

POULTRY RESEARCH

Professor K. Mather, C.B.E., D.SC., PH.D., F.R.S. (Chairman).
R. Coles, B.A., D.SC., PH.D., DIP.ED.
H. R. Finn.
S. K. Kon, D.SC., PH.D., F.R.I.C.
Sir John Ritchie, C.B., B.SC., F.R.C.V.S., D.V.S.M., F.R.S.E.
Alan Robertson, B.A., D.SC.
J. Sutton, M.B.E.
R. F. Gordon, D.SC., M.R.C.V.S. (Member and Technical Secretary).

SCRAPIE RESEARCH

R. E. Glover, M.A., D.SC., F.R.C.V.S. (Chairman).
E. A. Carmichael, C.B.E., D.SC., F.R.C.P.
W. S. Gordon, C.B.E., PH.D., M.R.C.V.S., F.R.S.E.
E. Weston Hurst, M.D., D.SC., F.R.C.P.
R. Markham, M.A., PH.D., F.R.S.
Professor L. P. Pugh, M.A., B.SC., F.R.C.V.S.
Sir John Ritchie, C.B., B.SC., F.R.C.V.S., D.V.S.M., F.R.S.E.
Professor E. T. C. Spooner, M.A., M.D.
Professor Lord Stamp, M.A., M.B., B.CHIR.
J. T. Stamp, D.SC., M.R.C.V.S., F.R.S.E.

DISEASES OF SHEEP AND CATTLE

Sir John Ritchie, C.B., B.SC., F.R.C.V.S., D.V.S.M., F.R.S.E. (Chairman).
H. I. Field, M.SC., M.R.C.V.S.
R. E. Glover, M.A., D.SC., F.R.C.V.S.
W. S. Gordon, C.B.E., PH.D., M.R.C.V.S., F.R.S.E.
Professor J. E. Nichols, M.SC., PH.D., F.R.S.E.
Professor Alex Robertson, M.A., B.SC., PH.D., M.R.C.V.S., F.R.I.C., F.R.S.E.
A. W. Stableforth, D.SC., M.R.C.V.S., D.V.S.M.
J. T. Stamp, D.SC., M.R.C.V.S., F.R.S.E.
Professor W. L. Weipers, B.SC., F.R.C.V.S., D.V.S.M., F.R.S.E.
J. M. Payne, B.SC., PH.D., M.R.C.V.S. (Technical Secretary).

PLANTS AND SOILS

ENVIRONMENT IN GLASSHOUSES

Professor J. W. Munro, C.B.E., M.A., D.SC. (Chairman).
Professor G. E. Blackman, M.A., F.R.S.
W. H. Cashmore, C.B.E., B.A., N.D.A.
E. Danter, M.A., A.INST.P.
Professor F. G. Gregory, D.SC., A.R.C.S., D.I.C., F.R.S.
Professor J. P. Hudson, M.B.E., G.M., M.SC., PH.D., N.D.H.
W. J. C. Lawrence, O.B.E., V.M.H.
E. R. Leonard, D.SC., A.R.C.S.
L. G. Morris, B.SC.(ENG.), A.F.R.A.E.S.
G. F. Sheard, M.SC.
L. P. Smith, B.A.
L. Stenning.
Principal M. A. H. Tincker, M.A., D.SC., F.L.S.
R. G. Voysey, A.C.G.I., A.M.I.MECH.E.
Professor C. P. Whittingham, B.A., PH.D.

FIELD WATER CONTROL

*R. K. Schofield, M.A., PH.D., F.INST.P. (Chairman).
Professor T. A. Bennet-Clark, M.A., PH.D., F.R.S.
W. H. Cashmore, C.B.E., B.A., N.D.A.
E. C. Childs, SC.D., PH.D.
Miss V. M. Conway, B.A., PH.D.
R. Glentworth, B.S.A., PH.D.
Sir Claude Inglis, C.I.E., M.A.I., M.I.C.E., F.R.S.
E. A. G. Johnson, C.B.E., B.SC., M.I.C.E., M.I.W.E.
W. O. Kinghorn, B.SC.
H. G. Lambert, M.A.
A. Muir, B.SC., PH.D.
H. H. Nicholson, M.B.E., M.A.
H. L. Penman, M.SC., PH.D., F.INST.P.
F. J. Richards, D.SC., F.R.S.
R. H. Smith, B.A.
D. J. Watson, M.A., PH.D.
Rice Williams, O.B.E., D.SC.

*Died 8th June, 1960

HOP RESEARCH

Professor T. Wallace, C.B.E., M.C., D.SC., F.R.I.C., V.M.H., F.R.S. (Chairman).
G. D. H. Bell, B.SC., PH.D.
A. H. Cook, D.SC., F.R.I.C., F.R.S.
A. Cronk.
H. S. Darling, B.SC., PH.D., M.AGR., A.I.C.T.A., M.I.BIOL.
H. J. Hamblin, O.B.E., B.A.
R. V. Harris, D.SC., A.R.C.S., D.I.C., M.I.BIOL.
W. G. Keyworth, PH.D., A.R.C.S., D.I.C., M.I.BIOL.
W. C. Moore, C.B.E., M.A.
Sir Thomas Neame.
J. Nott, M.B.E., J.P.
N. B. Smiley.
Professor R. L. Wain, D.SC., PH.D., F.R.I.C., F.R.S.

POTATO PROBLEMS

Sir William G. Ogg, M.A., B.SC., PH.D., LL.D., F.R.S.E. (Chairman)
F. C. Bawden, M.A., F.R.S.
G. D. H. Bell, B.SC., PH.D.
W. Black, D.SC., PH.D., F.R.S.E.
K. S. Dodds, D.SC., PH.D.
J. L. Hardie, D.SC.
F. R. Horne, C.B.E., M.A., N.D.A., N.D.D.
E. C. Large, B.SC., A.R.I.C.
David Lowe, C.B.E., F.R.S.E.
Mrs. N. McDermott, M.B.E., M.SC.
J. Marshall.
Professor F. L. Milthorpe, M.SC., PH.D., D.I.C.
A. C. Owers, M.A.
Professor Alexander Robertson, M.A., B.SC., PH.D., LL.D., F.R.S.
R. G. Tomkins, M.A., PH.D.
A. R. Wilson, B.SC., M.S., PH.D.

GROUPS

ANIMALS

CARCASE QUALITY STUDIES

R. Scarisbrick, M.A., PH.D., M.R.C.V.S., A.R.I.C. (Chairman).

A. J. Brookes, M.A.

F. R. Gerrard, M.B.E.

Sir John Hammond, C.B.E., M.A., D.S.C., F.R.S.

K. Bryce Jones, B.S.C., PH.D.

J. W. B. King, M.A., PH.D.

G. E. Lamming, B.S.C., M.S., PH.D.

R. A. Lawrie, PH.D., A.R.I.C.

P. J. Macfarlan, B.S.C., N.D.A., N.D.D.

I. L. Mason, B.A.

R. W. Pomeroy, M.A., PH.D.

T. R. Preston, B.S.C., PH.D.

J. C. Tayler, M.A., DIP.AGRIC.

COLLABORATIVE TESTS OF PROTEIN QUALITY IN ANIMAL FEEDING STUFFS

S. K. Kon, D.S.C., PH.D., F.R.I.C. (Chairman).

*A. E. Bender, B.S.C., PH.D., A.R.I.C.

A. A. Bindloss, B.S.C., DIP.AGRIC.

*A. W. Boyne, B.S.C.

*K. J. Carpenter, M.A., B.S.C., PH.D.

Marie E. Coates, PH.D., F.P.S.

*W. F. J. Cuthbertson, B.S.C., PH.D., F.R.I.C., M.I.BIOL.

♂J. Duckworth, B.S.A., D.S.C., F.R.S.E.

Kathleen M. Henry, B.S.C., PH.D.

A. E. Humphreys.

D. B. Lisle, B.S.C., PH.D., A.R.I.C.

D. S. Miller, B.S.C.

†F. H. Moulton, M.S.C.

*W. R. Muir, B.S.C.

June N. Olley, PH.D.

S. A. Price, B.S.C., F.R.I.C.

G. D. Rosen, B.S.C., PH.D., F.R.I.C.

G. Walley, B.S.C., F.R.I.C.

A. L. Walther, M.A., M.R.C.V.S.

*A. A. Woodham, B.S.C., PH.D.

* Also member of the Group's Steering Committee.

† Chairman of the Group's Steering Committee.

♂ Died 11th April, 1960.

OESTROGENS

(Appointed in consultation with the M.R.C.)

Professor Sir Solly Zuckerman, C.B., M.A., M.D., D.S.C., F.R.S. (Chairman).

P. M. F. Bishop, D.M.

W. E. Bowden.

Professor Sir Charles Dodds, M.V.O., D.S.C., PH.D., M.D., F.R.C.P., F.R.I.C., F.R.S.

S. J. Folley, D.S.C., PH.D., F.R.S.

R. F. Glascock, B.S.C., PH.D.

G. E. Lamming, B.S.C., M.S., PH.D.

A. S. Parkes, C.B.E., M.A., SC.D., F.R.S.

T. R. Preston, B.S.C., PH.D.

PLANTS AND SOILS

COMPARISON OF METHODS OF ANALYSIS OF MINERAL ELEMENTS IN PLANTS

J. B. E. Patterson, M.SC., F.R.I.C. (Chairman).
M. Allen, B.SC.
C. Bould, M.SC., PH.D.
W. M. Crooke, B.SC., PH.D., A.R.I.C.
E. J. Hewitt, B.SC., PH.D., A.K.C.
E. C. Humphries, D.SC.
A. C. Mason, B.SC., F.R.I.C.
R. L. Mitchell, B.SC., PH.D., F.R.I.C., F.R.S.E.
D. J. D. Nicholas, D.SC., PH.D., A.K.C., F.R.I.C.
F. H. Vanstone, B.SC., PH.D., A.INST.P.
R. C. Warren, B.SC.

A.R.C. SCHOLARSHIPS COMMITTEE

Sir William K. Slater, K.B.E., D.SC., F.R.I.C., F.R.S. (Chairman of Main Committee).

BOTANY GROUP

Professor T. A. Bennet-Clark, M.A., PH.D., F.R.S. (Chairman).
Professor P. H. Gregory, D.SC., D.I.C.
Professor K. Mather, C.B.E., D.SC., PH.D., F.R.S.
Professor W. T. Williams, D.SC., PH.D.

CHEMISTRY GROUP

E. G. COX, T.D., D.SC., F.INST.P., F.R.I.C., F.R.S. (Chairman).
Professor R. A. Morton, D.SC., PH.D., F.R.I.C., F.R.S.
N. W. Pirie, M.A., F.R.S.
Professor R. L. Wain, D.SC., PH.D., F.R.I.C.

ENGINEERING GROUP

W. H. Cashmore, C.B.E., B.A., N.D.A.
Professor E. M'Ewen, M.SC., M.I.MECH.E.
Professor W. A. Tuplin, D.SC., M.I.MECH.E.

ENTOMOLOGY GROUP

Professor V. B. Wigglesworth, C.B.E., M.A., M.D., B.CHIR., F.R.S. (Chairman).
I. Thomas, M.SC., PH.D.
C. B. Williams, M.A., SC.D., F.R.S.
D. W. Wright, M.A.

STATISTICS GROUP

D. J. Finney, M.A., SC.D., F.R.S., F.R.S.E.
F. Yates, SC.D., F.R.S.

ZOOLOGY GROUP

Professor, C. F. A. Pantin, M.A., SC.D., F.R.S. (Chairman).
J. B. Brooksby, D.SC., PH.D., M.R.C.V.S.
H. P. Donald, D.SC., PH.D., F.R.S.E.
Professor J. E. Harris, M.A., PH.D.
Professor J. W. Howie, M.D., M.R.C.P.
A. W. Stableforth, D.SC., M.R.C.V.S., D.V.S.M.

INTERDEPARTMENTAL AND JOINT COMMITTEES

JOINT A.I.C./A.R.C. COMMITTEE

A. B. Stewart, M.A., B.SC., PH.D., F.R.I.C., F.R.S.E. (Chairman).
J. F. Duncan, LL.D.
R. E. Glover, M.A., D.SC., F.R.C.V.S.
Professor Sir Joseph B. Hutchinson, C.M.G., SC.D., F.R.S.
F. Rayns, C.B.E., M.A.
H. G. Sanders, M.A., PH.D.
A. R. Wannop, O.B.E., B.ENG., F.R.S.E.

JOINT A.R.C./M.R.C./D.C. COMMITTEE ON BIOLOGICAL PROBLEMS (NON-MEDICAL) OF NUCLEAR PHYSICS

Sir James Denby Roberts, Bart., O.B.E., J.P. (Chairman).
W. G. Alexander, C.B.E., M.A.
H. R. Barnell, M.A., B.SC., PH.D., M.I.BIOL.
Professor G. E. Briggs, M.A., F.R.S.
R. J. Garner, M.A., M.V.SC., A.R.I.C., F.R.C.V.S.
R. F. Glascock, B.SC., PH.D.
Professor J. E. Harris, M.A., PH.D.
A. W. Kenny, M.A., B.SC., F.R.I.C.
J. F. Loutit, C.B.E., D.M., F.R.C.P.
A. S. McLean, M.B., CH.B., D.I.H., D.P.H.
W. G. Marley, O.B.E., M.SC., PH.D.
R. Scott Russell, M.A., M.SC., PH.D.
H. G. Sanders, M.A., PH.D.
A. W. Stableforth, D.SC., M.R.C.V.S., D.V.S.M.
E. B. Worthington, M.A., PH.D.

MANAGING SUB-COMMITTEE ON MONITORING

J. F. Loutit, C.B.E., D.M., F.R.C.P. (Chairman).
N. T. J. Bailey, M.A., D.SC.
K. L. Blaxter, D.SC., PH.D., N.D.A.
F. J. Bryant, B.SC., PH.D., D.I.C., A.R.C.S.
D. J. Finney, M.A., SC.D., F.R.S., F.R.S.E.
Miss D. F. Hollingsworth, O.B.E., B.SC., M.I.BIOL.
J. L. McGirr, B.SC., M.R.C.V.S.
W. G. Marley, O.B.E., M.SC., PH.D.
Professor W. V. Mayneord, C.B.E., D.SC., F.I.P.
E. R. Mercer, B.SC.
R. Scott Russell, M.A., M.SC., PH.D.
C. L. Smith, M.A., PH.D.
*R. K. Schofield, M.A., PH.D., F.INST.P.

* Died 8th June, 1960.

Published by
HER MAJESTY'S STATIONERY OFFICE

To be purchased from
York House, Kingsway, London w.c.2
423 Oxford Street, London w.1
13A Castle Street, Edinburgh 2
109 St. Mary Street, Cardiff
39 King Street, Manchester 2
50 Fairfax Street, Bristol 1
2 Edmund Street, Birmingham 3
80 Chichester Street, Belfast 1
or through any bookseller

Printed in England